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Hack et al.

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(54) **METHOD OF FABRICATING A 3-DIMENSIONAL STRUCTURE, MESH FORMWORK ELEMENT FOR FABRICATING A 3-DIMENSIONAL STRUCTURE AND METHOD OF FABRICATING THE SAME**

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B28B 23/00 (2006.01)
B28B 23/02 (2006.01)

(52) **U.S. Cl.**
CPC ***B28B 23/005*** (2013.01); ***B28B 23/0006*** (2013.01); ***B28B 23/02*** (2013.01); ***B29C 70/26*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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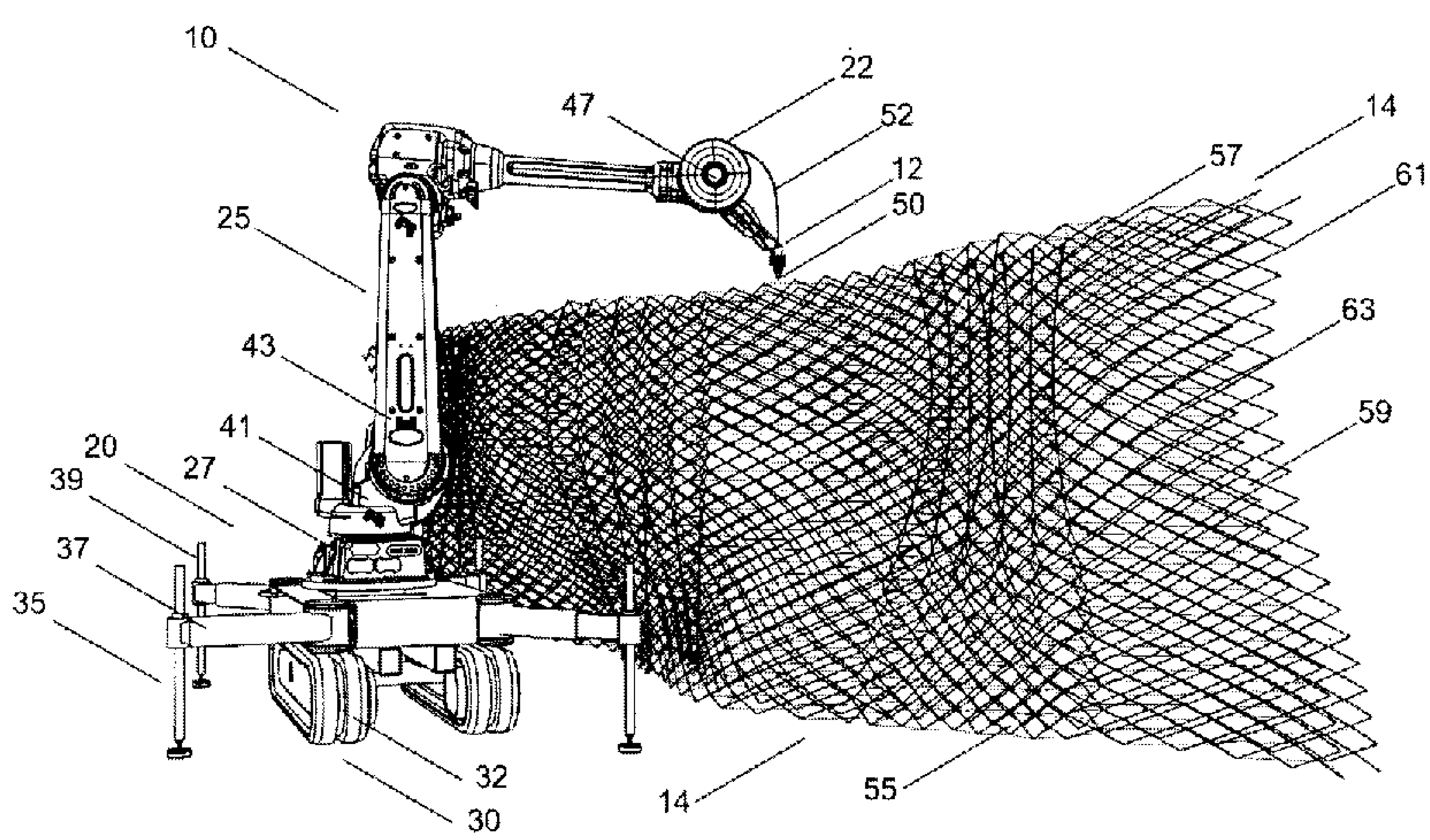

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(57) **ABSTRACT**

Method of fabricating a 3-dimensional structure, mesh formwork element for fabricating a 3-dimensional structure, and method of fabricating the same. The method of fabricating a 3-dimensional structure comprises providing a mesh formwork element such that a cavity bound by at least two opposing portions of the mesh formwork is formed; accumulating a material in the cavity; and allowing the material to harden; wherein apertures in the at least two opposing portions of the mesh formwork element are adapted to the hydro-static pressure of the accumulated material or vice versa such that at least two surfaces of the hardened material substantially take on the respective shapes defined by the two opposing portions of the mesh formwork element.

24 Claims, 16 Drawing Sheets

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Oct. 17, 2018 Office Action issued in European Patent Application No. 14 842 848.5.

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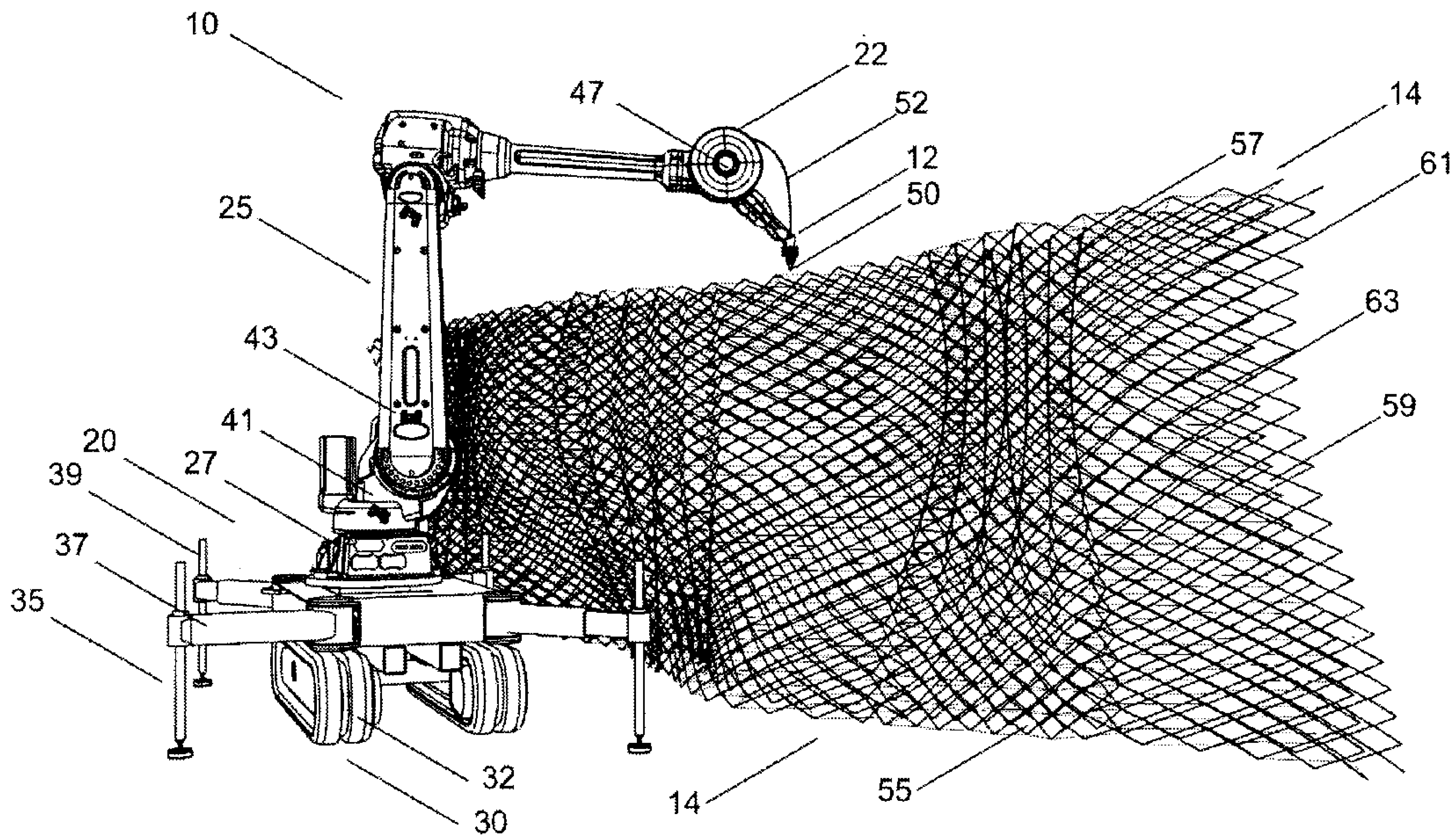


Fig. 1

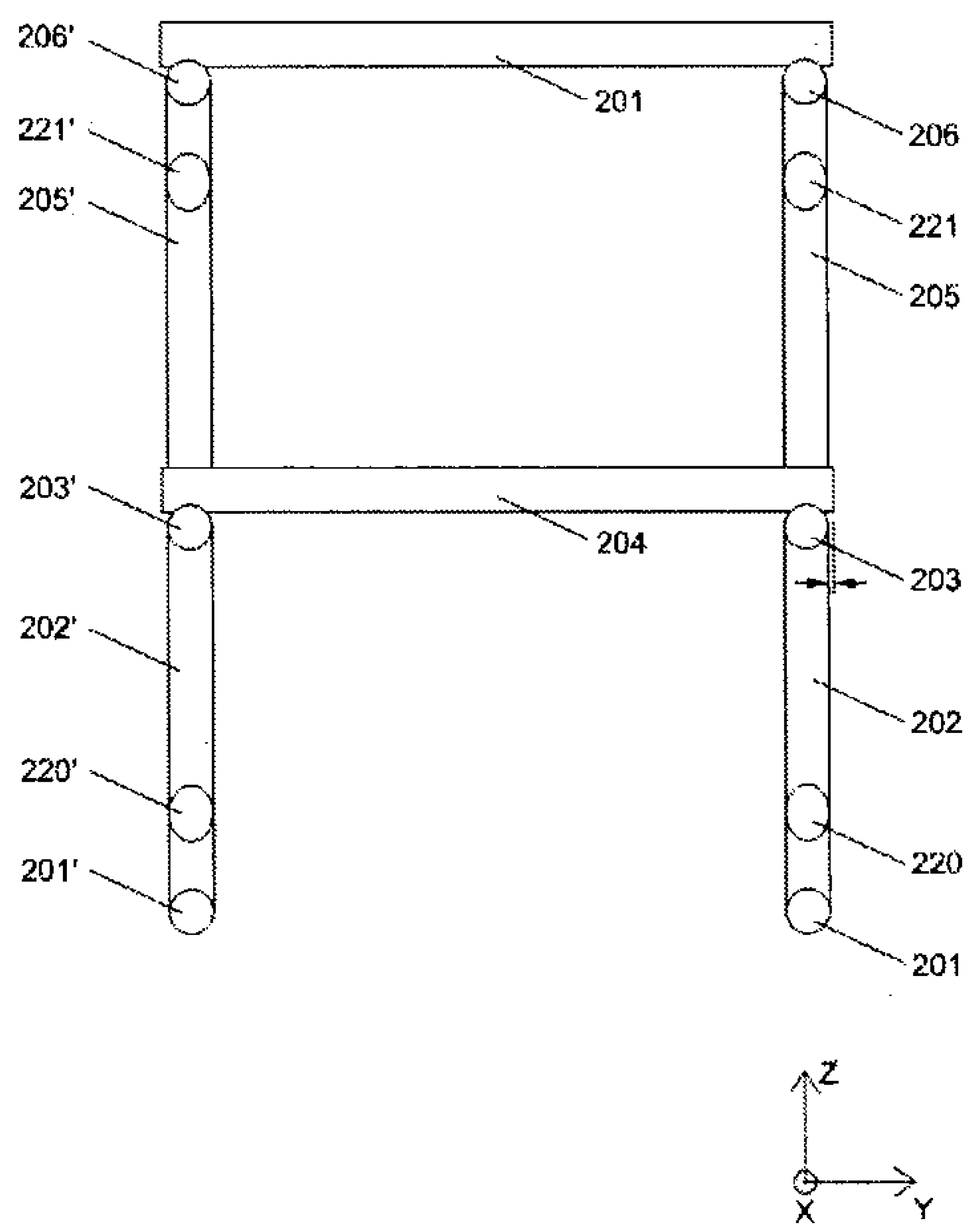

206'
201
206
221'
205'
221
205
203'
204
203
202'
202
220'
220
201'
201
Z
X
Y

Fig. 2

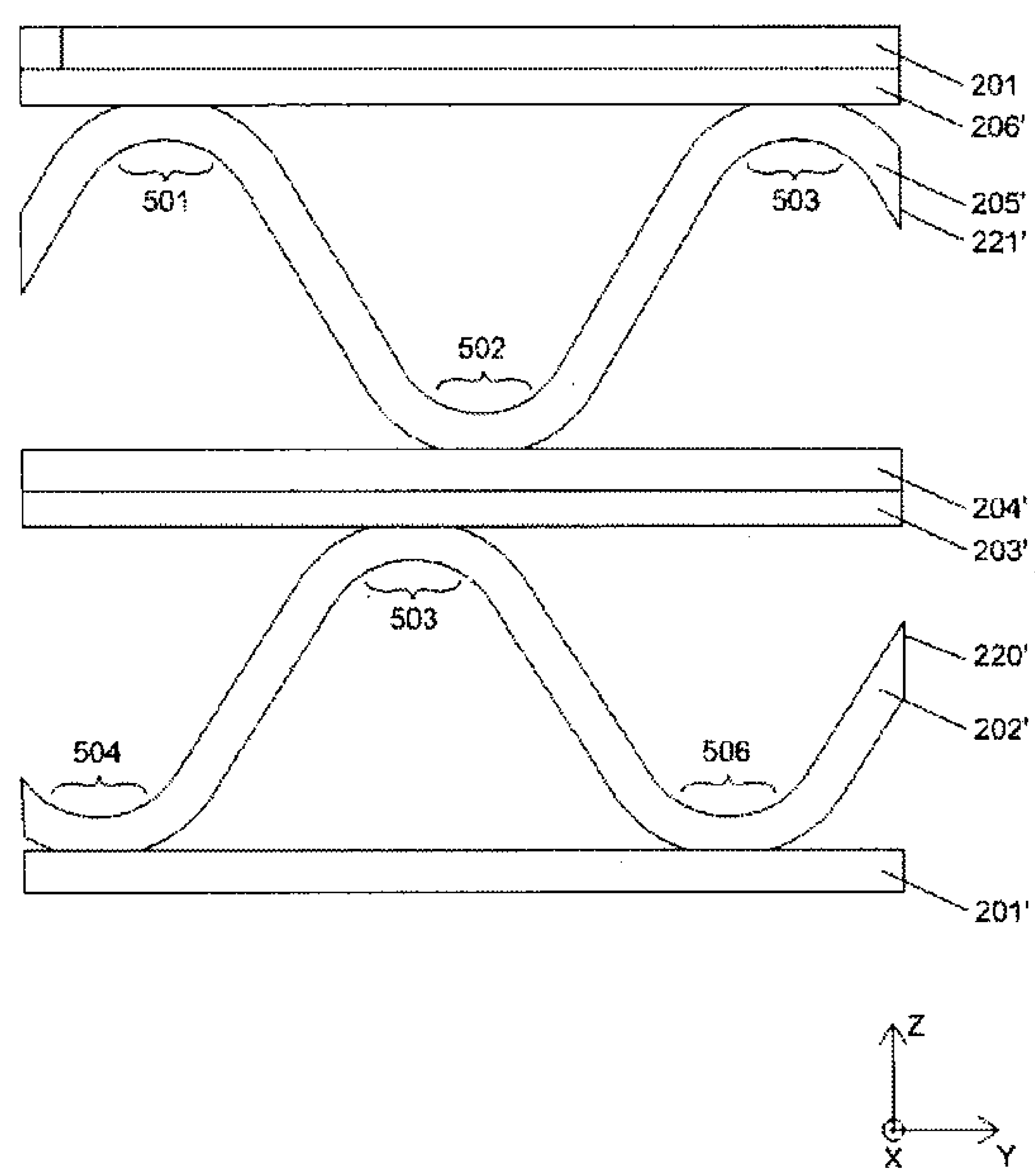

201
206'
501
503
205'
221'
502
204'
203'
503
220'
202'
504
506
201'
Z
X
Y

Fig. 3

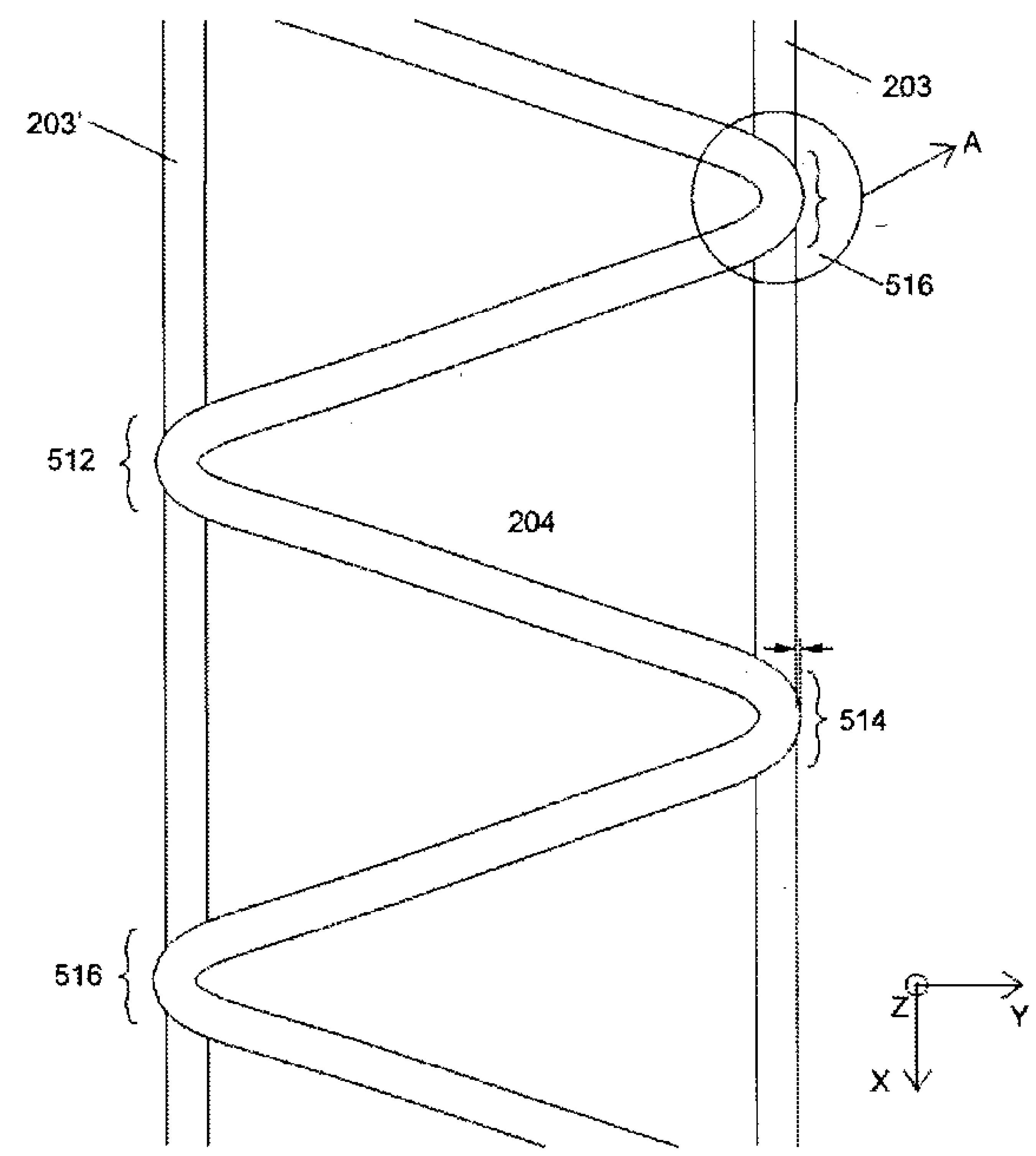


Fig. 4

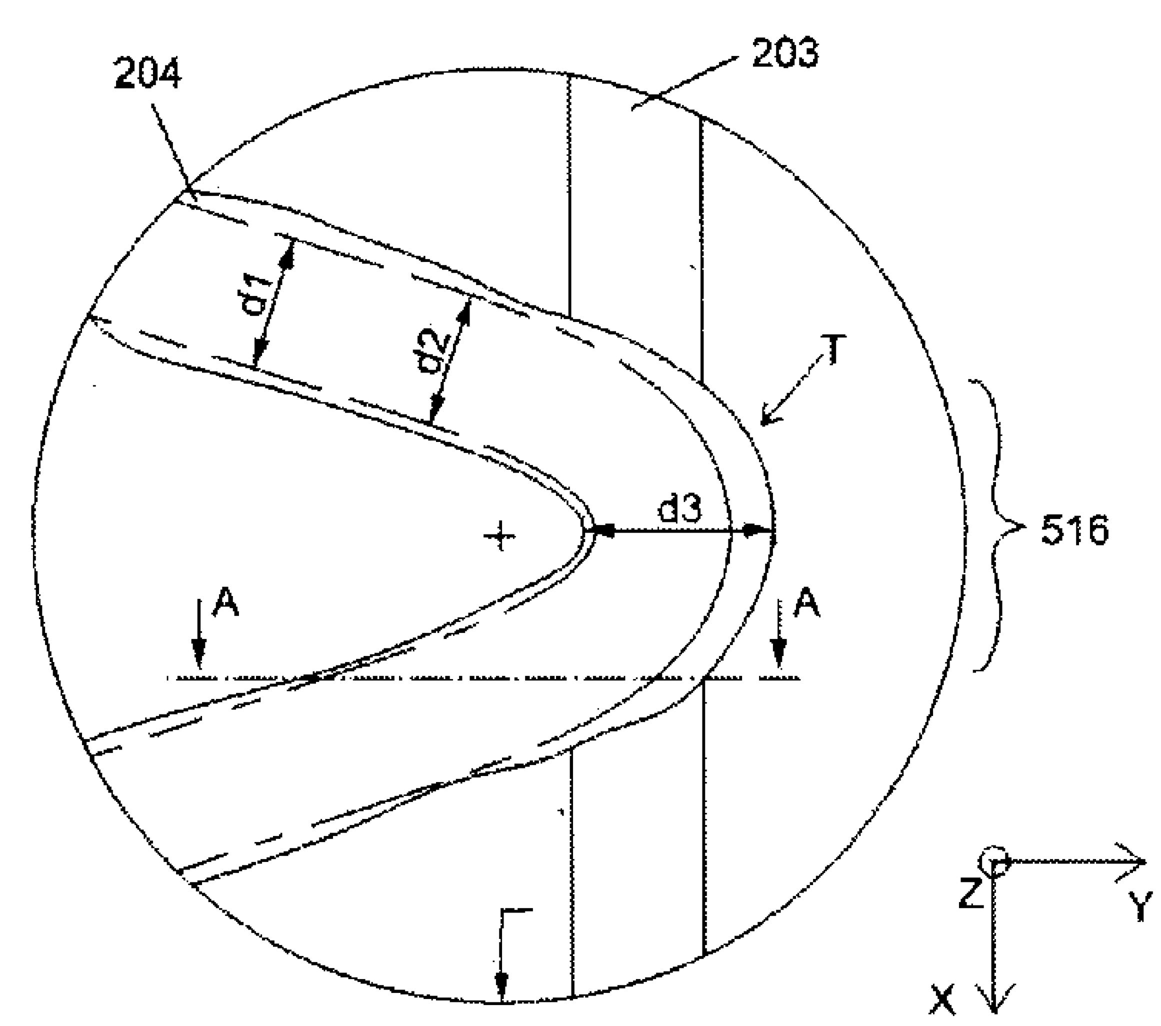


Fig. 5

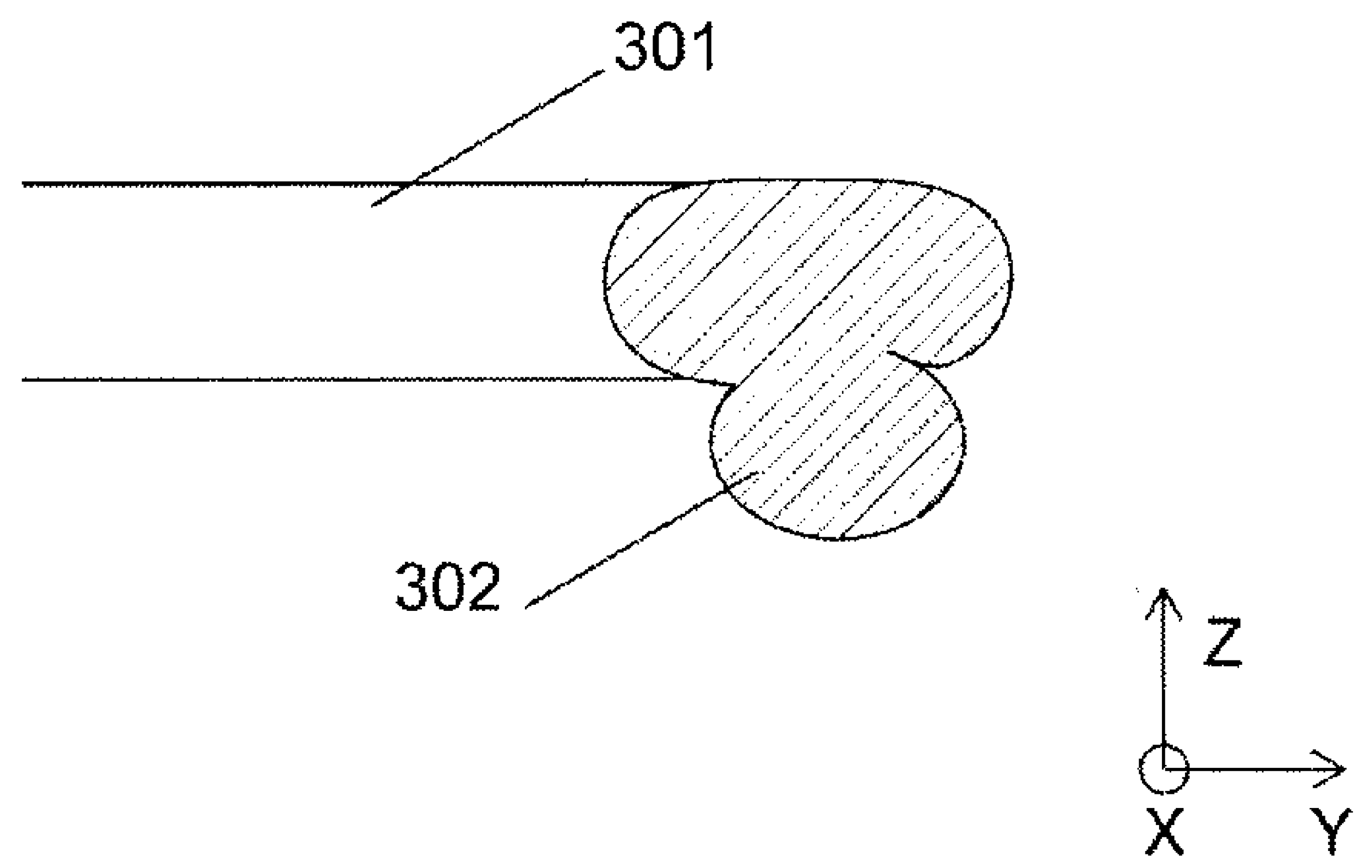


Fig. 6

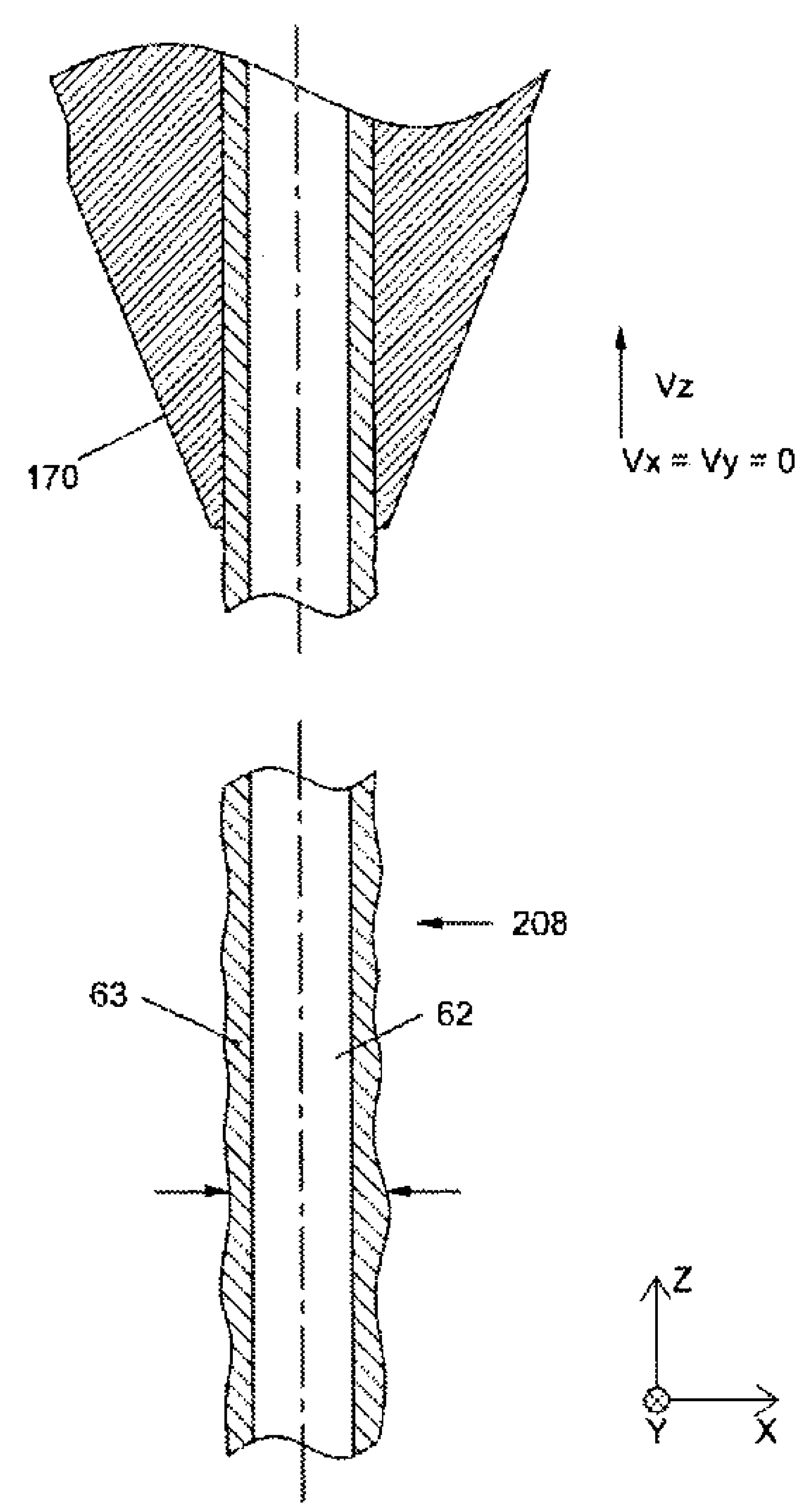
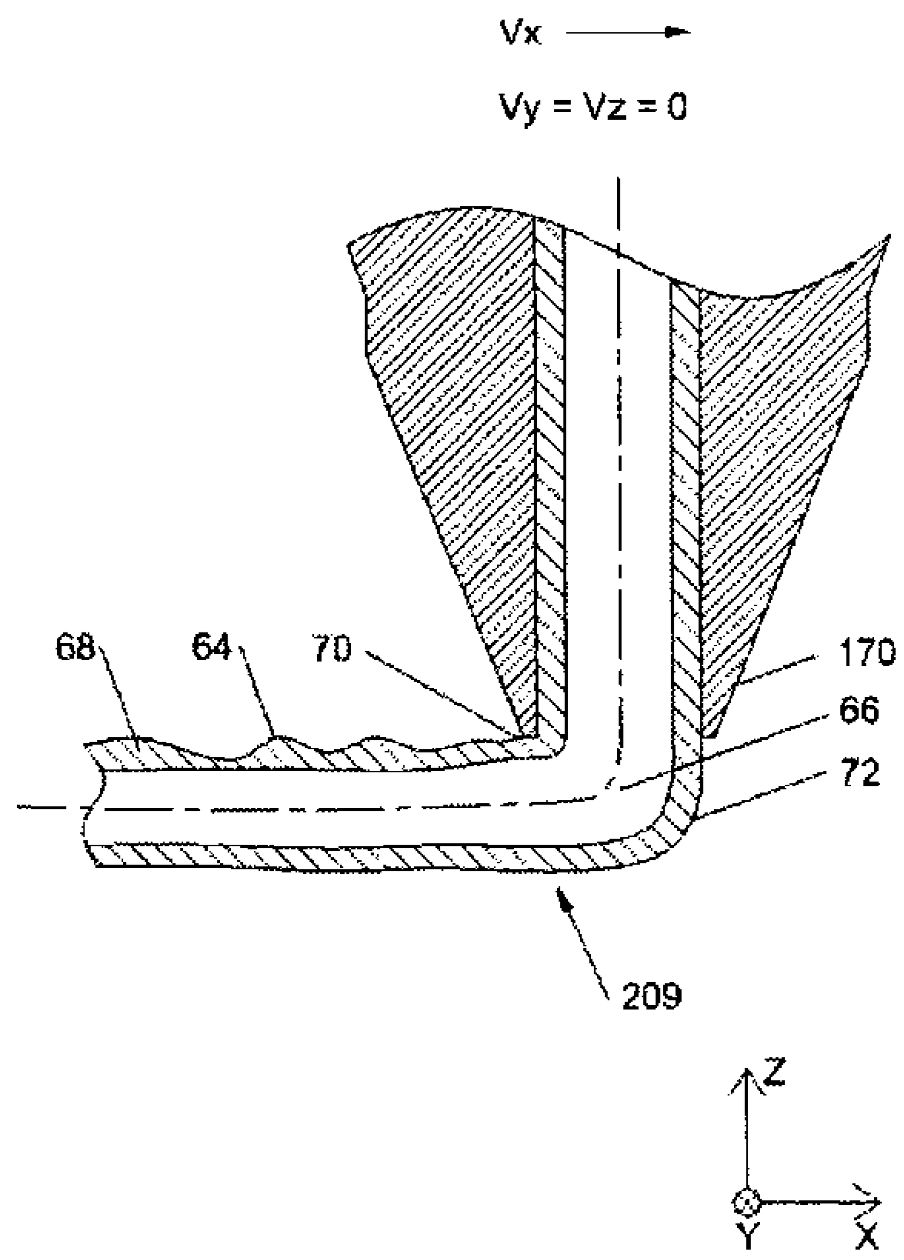


Fig. 7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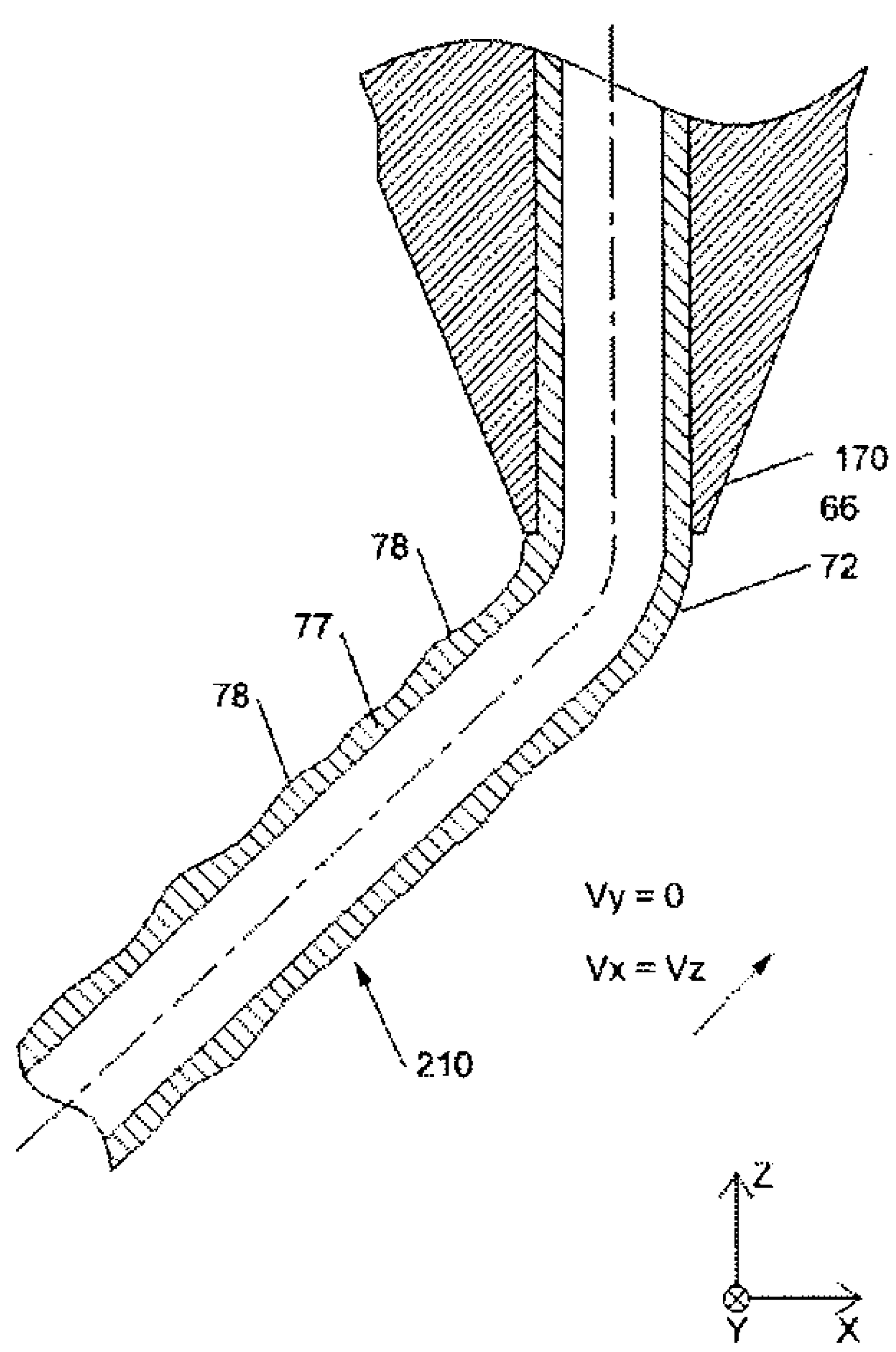
Vy = Vz = 0
68
64
70
170
66
72
209
Z
Y
X

Fig. 8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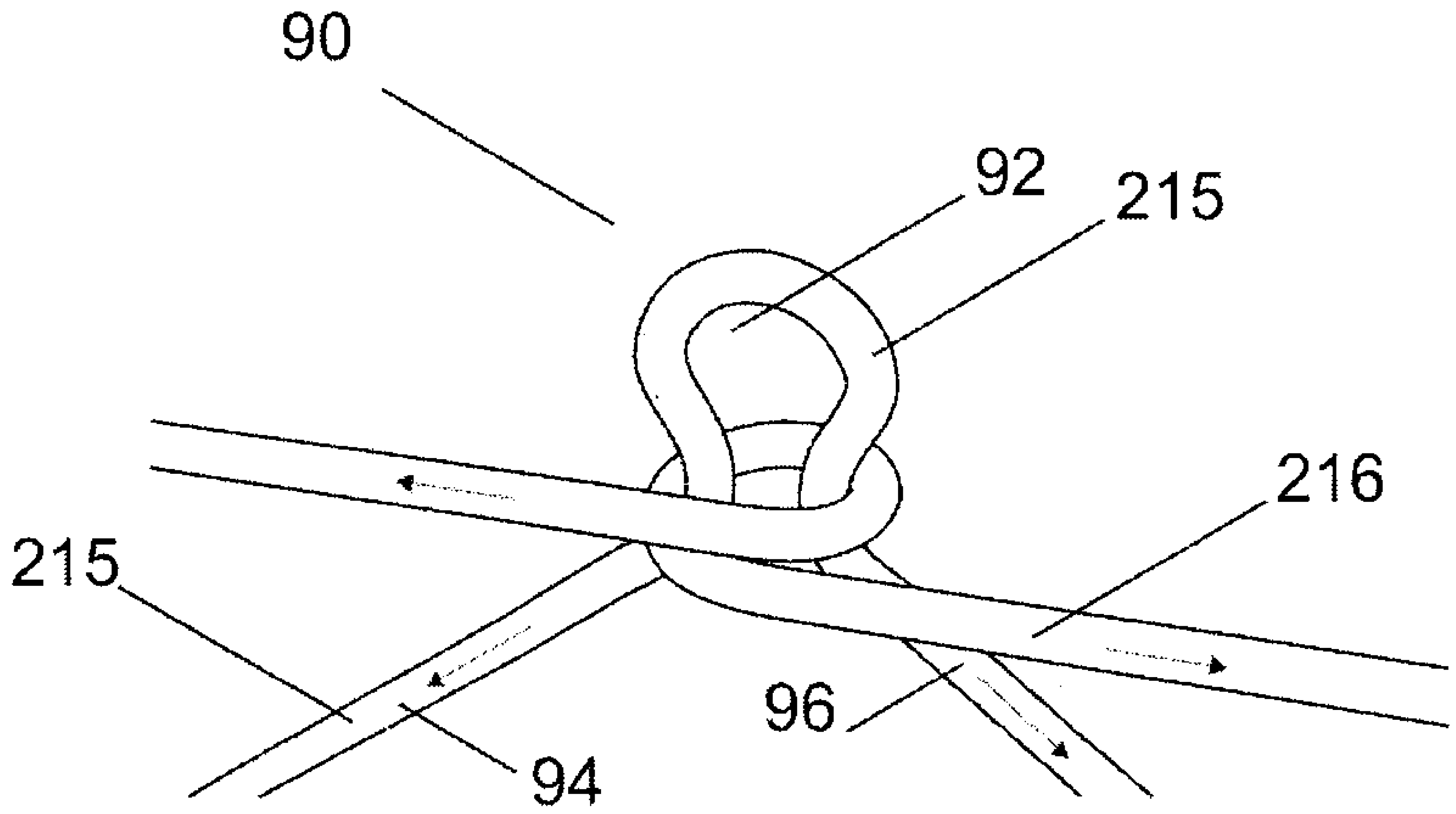
66
72
78
77
78
Vy = 0
Vx = Vz
210
Z
Y
X

Fig. 9



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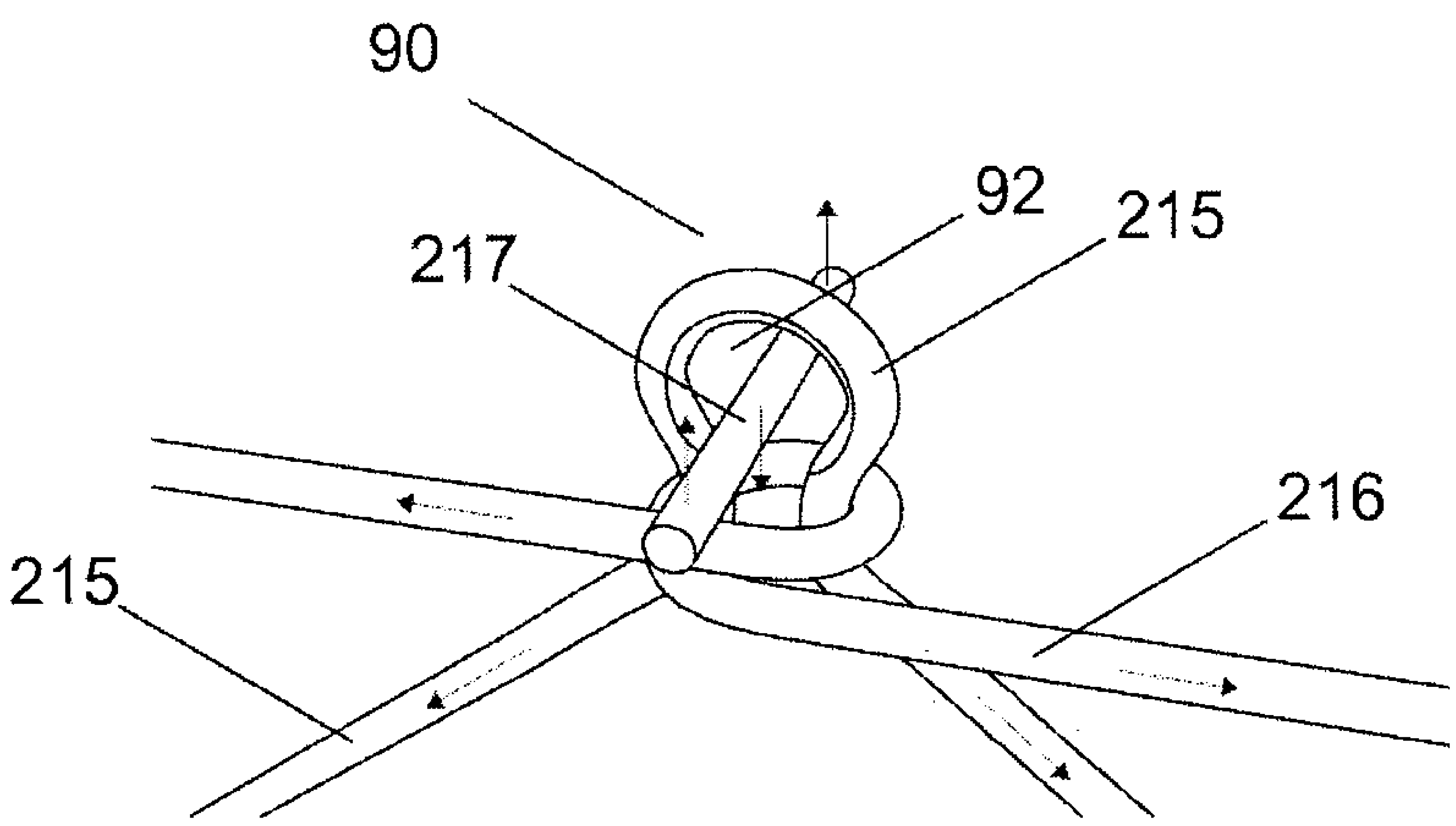

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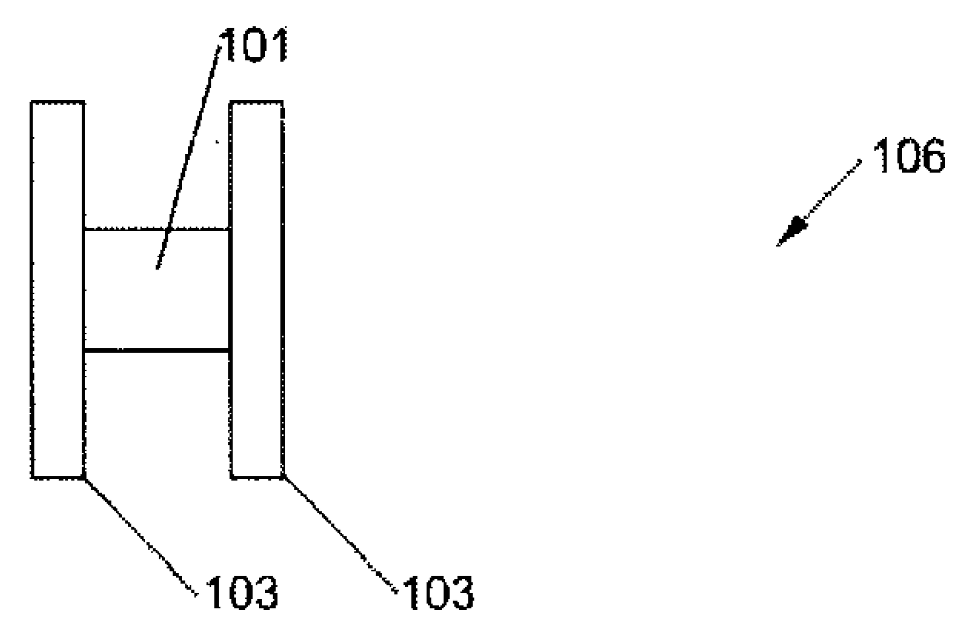

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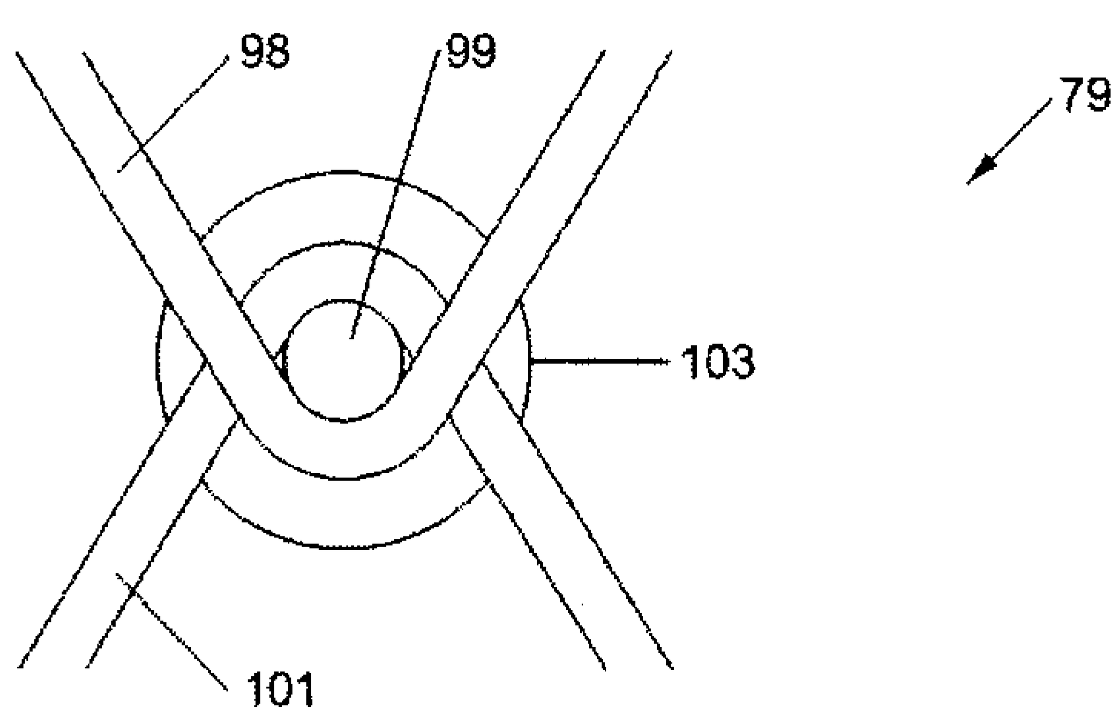


Fig. 13

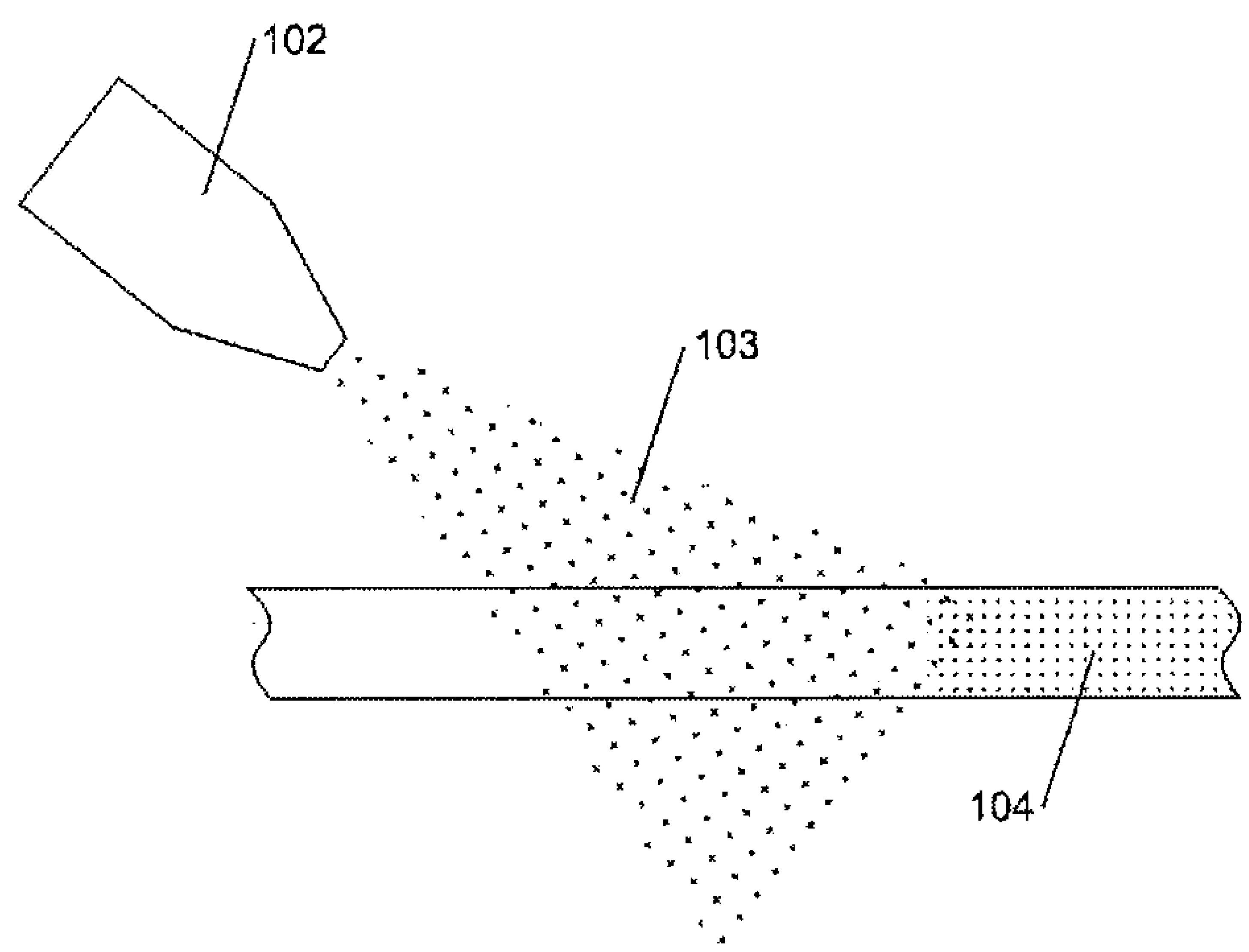


Fig. 14

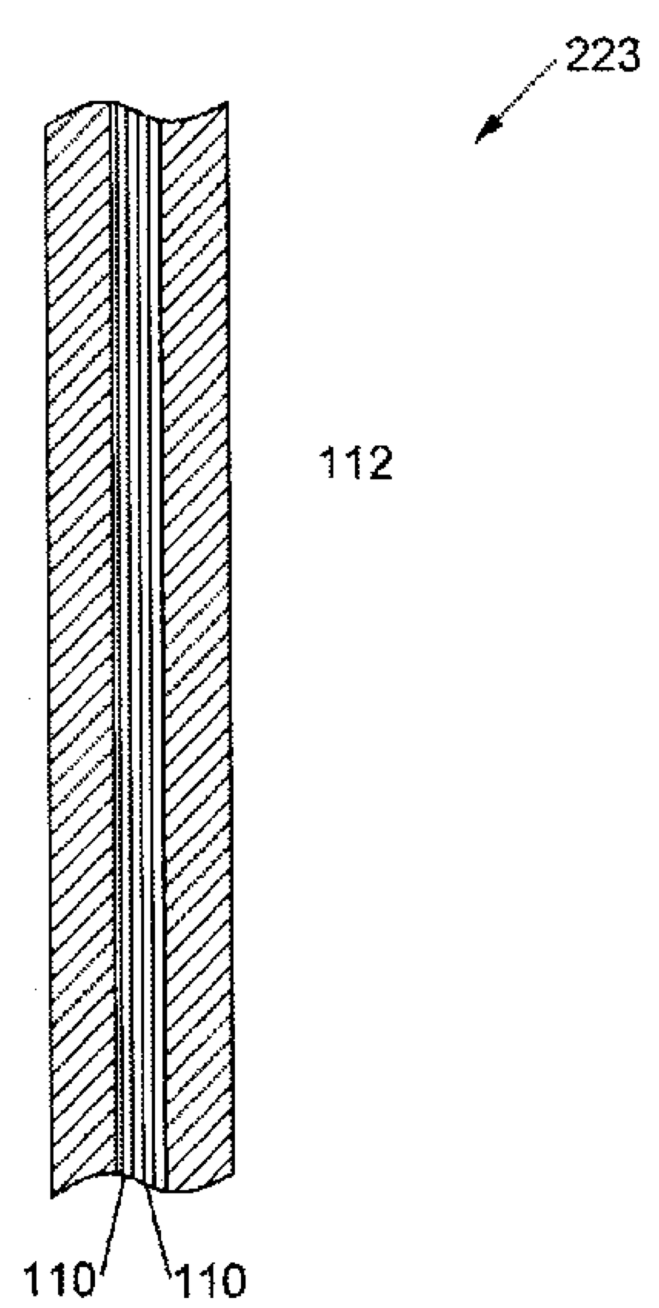


Fig. 15

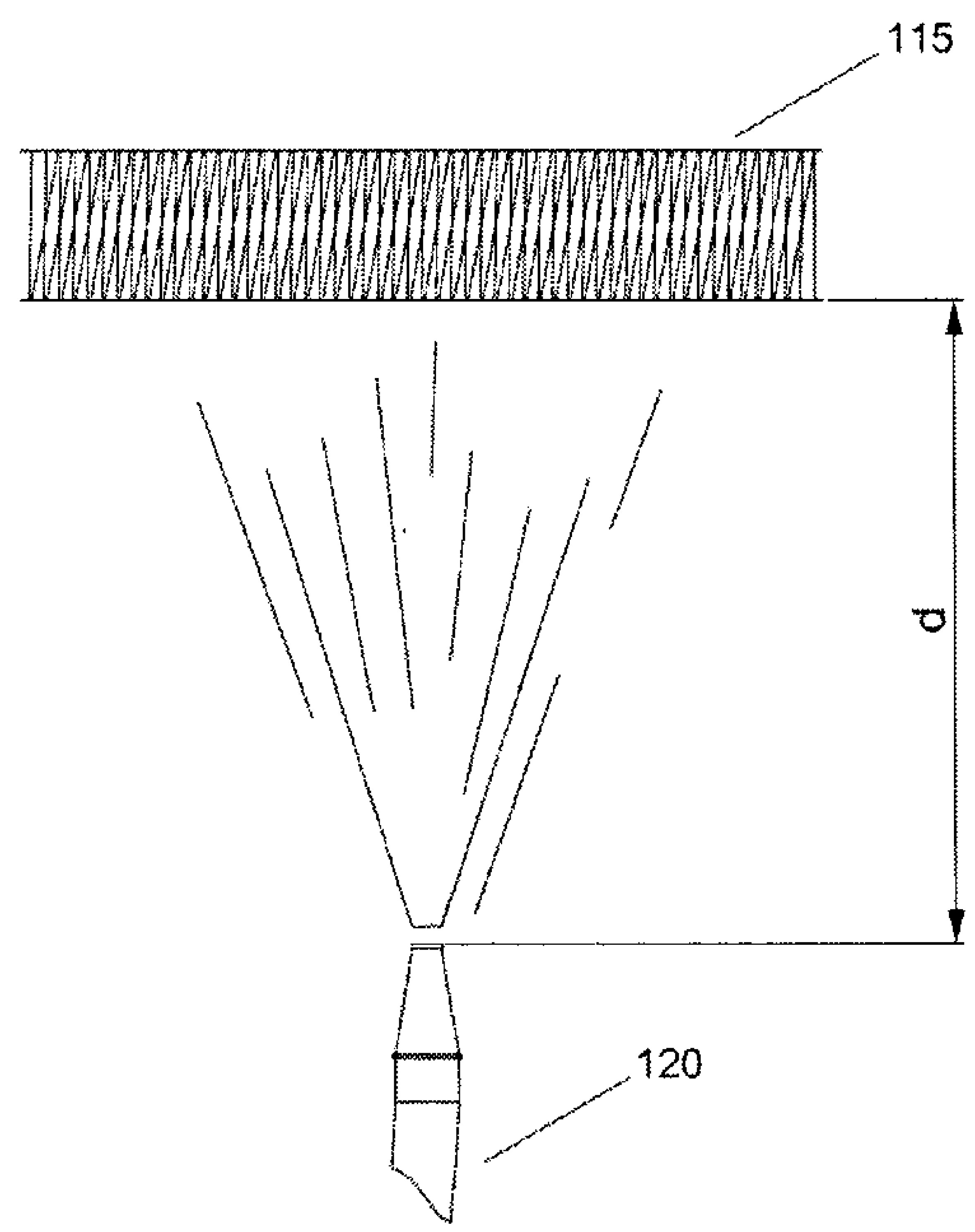


Fig. 16

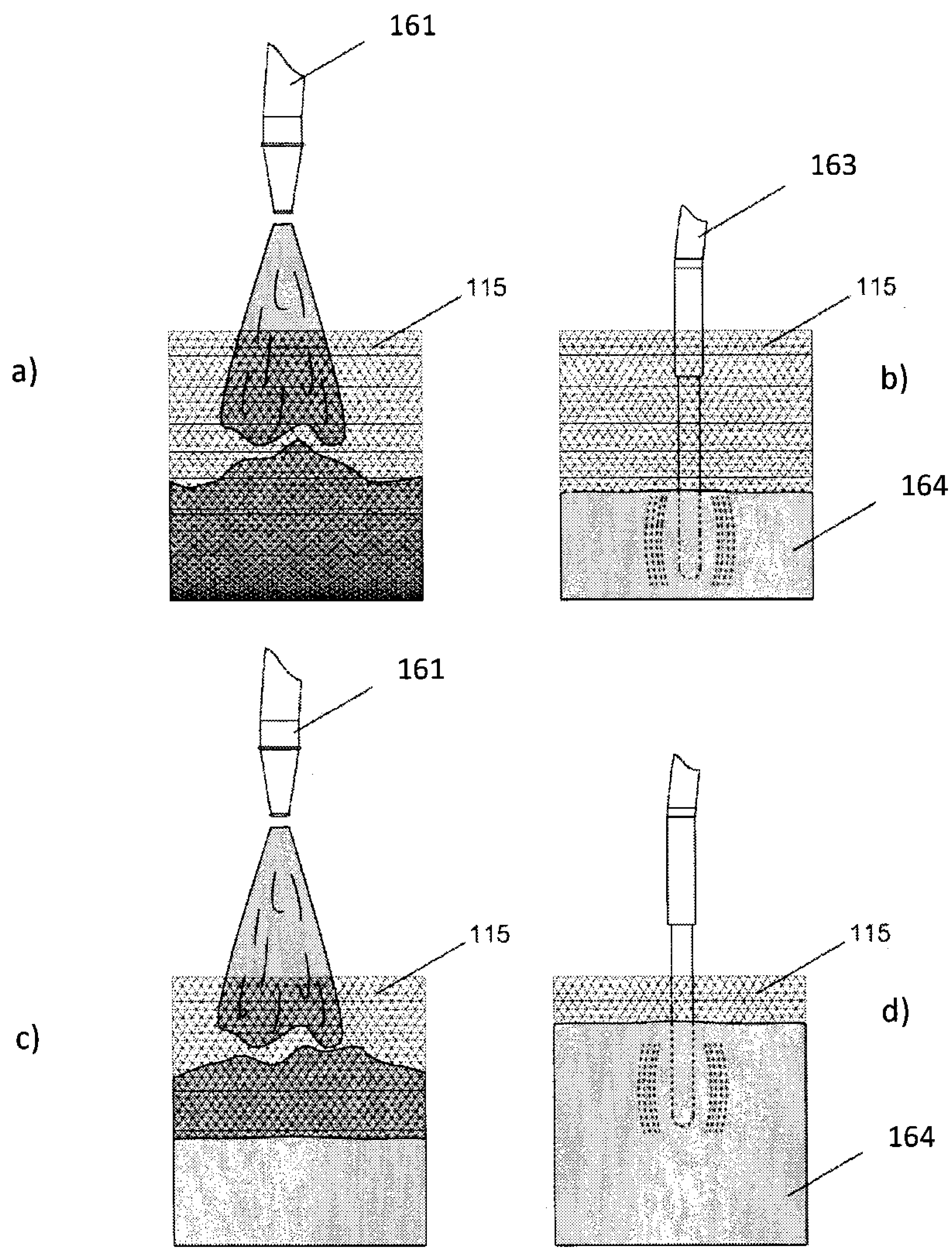


Fig. 17

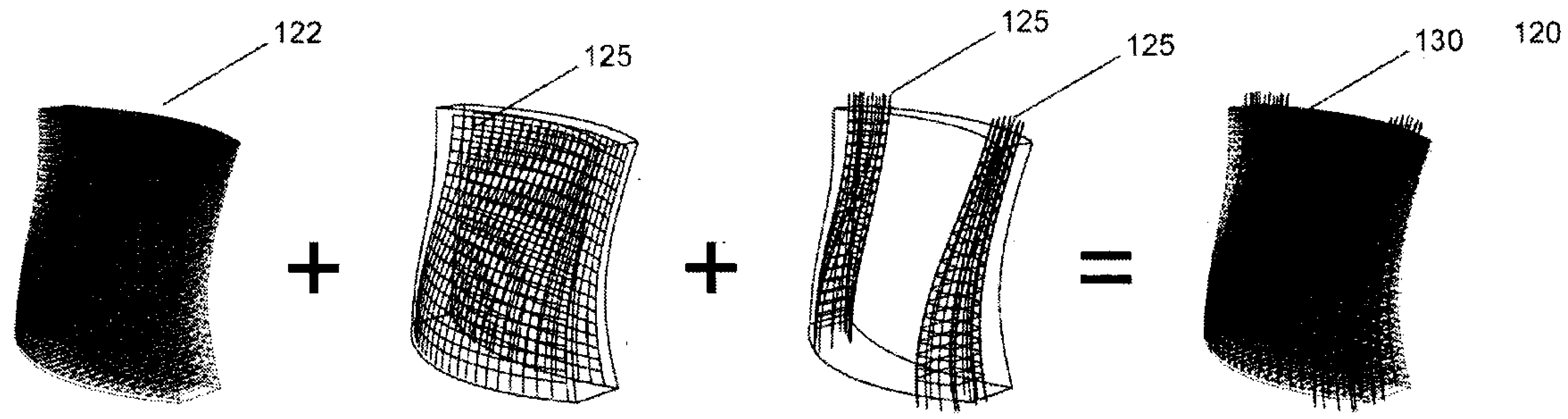
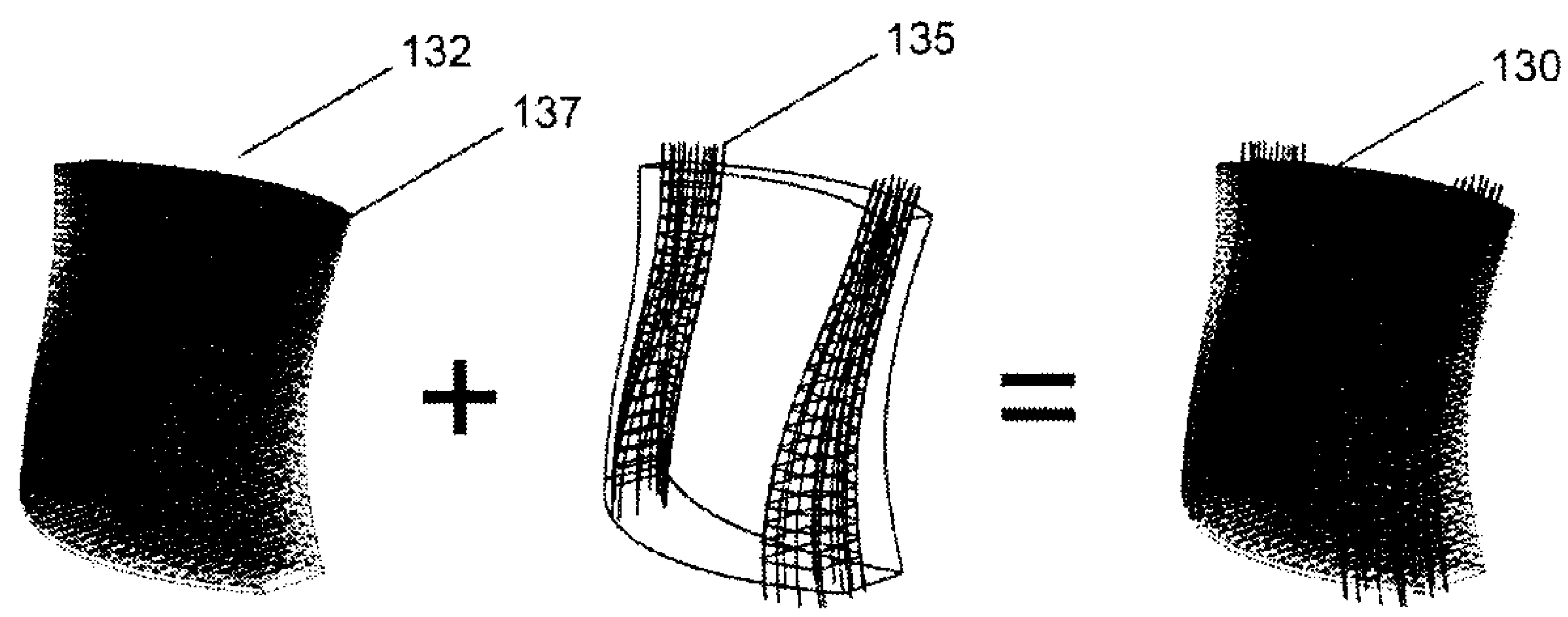


Fig. 18



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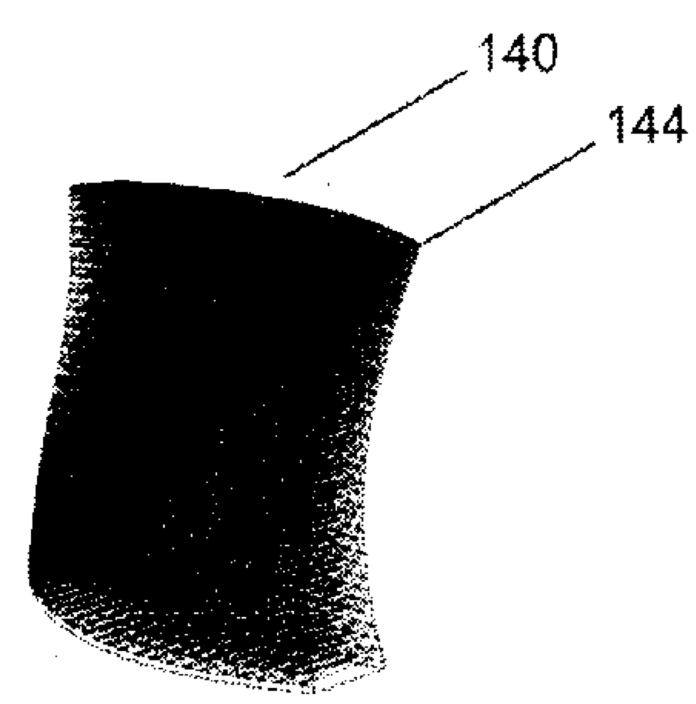

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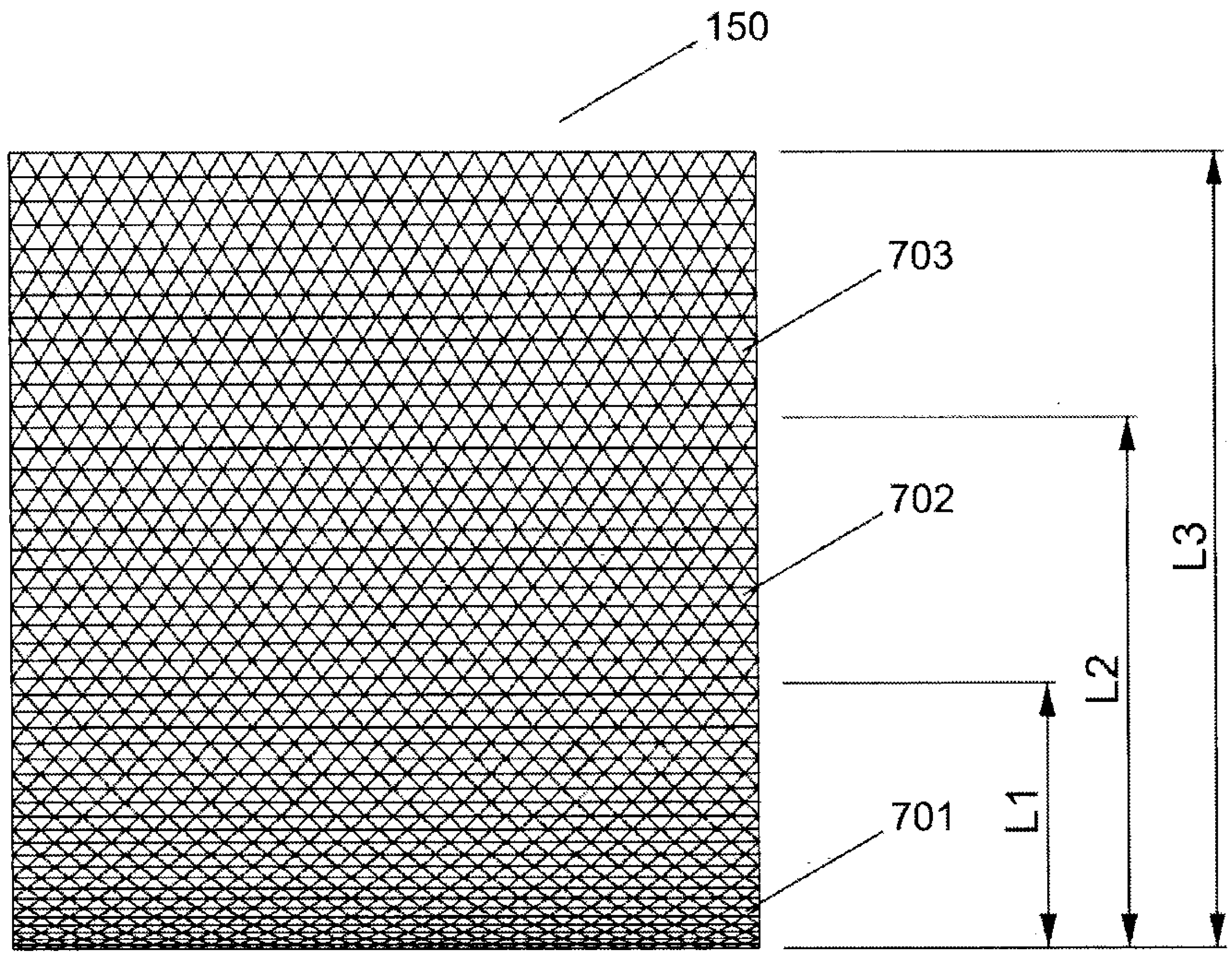

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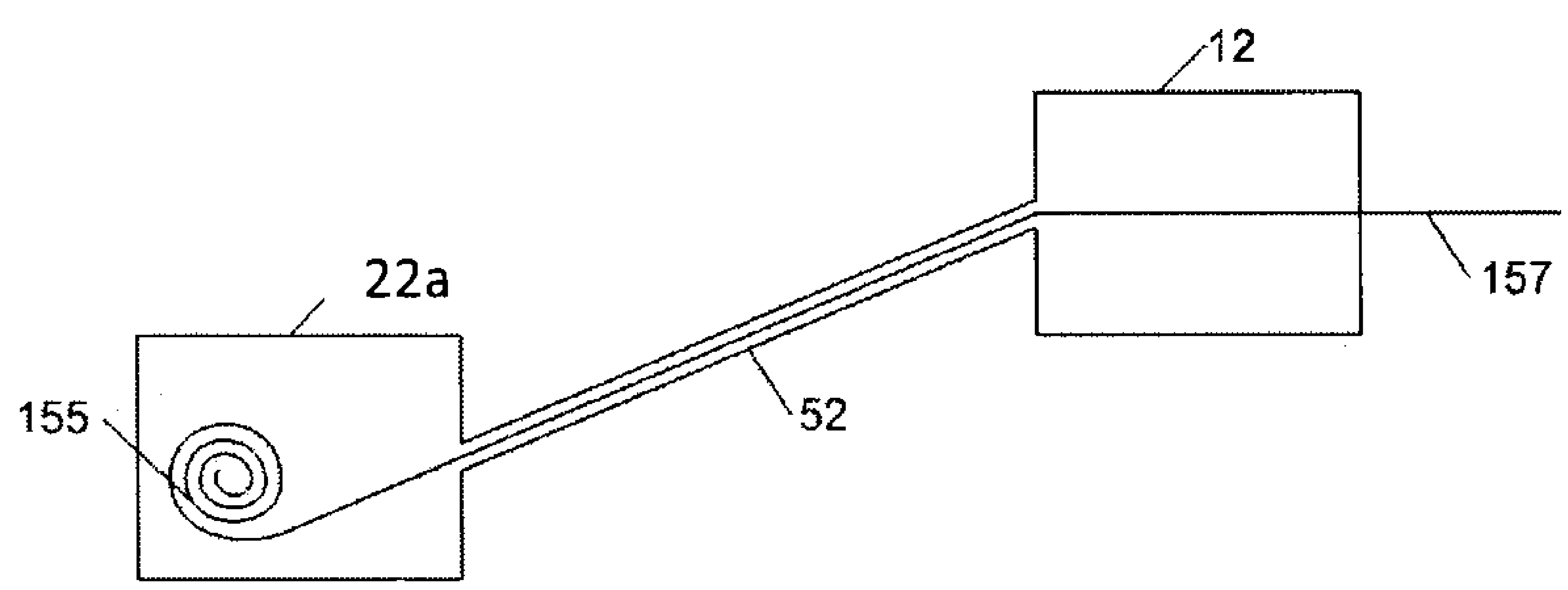

Fig. 22

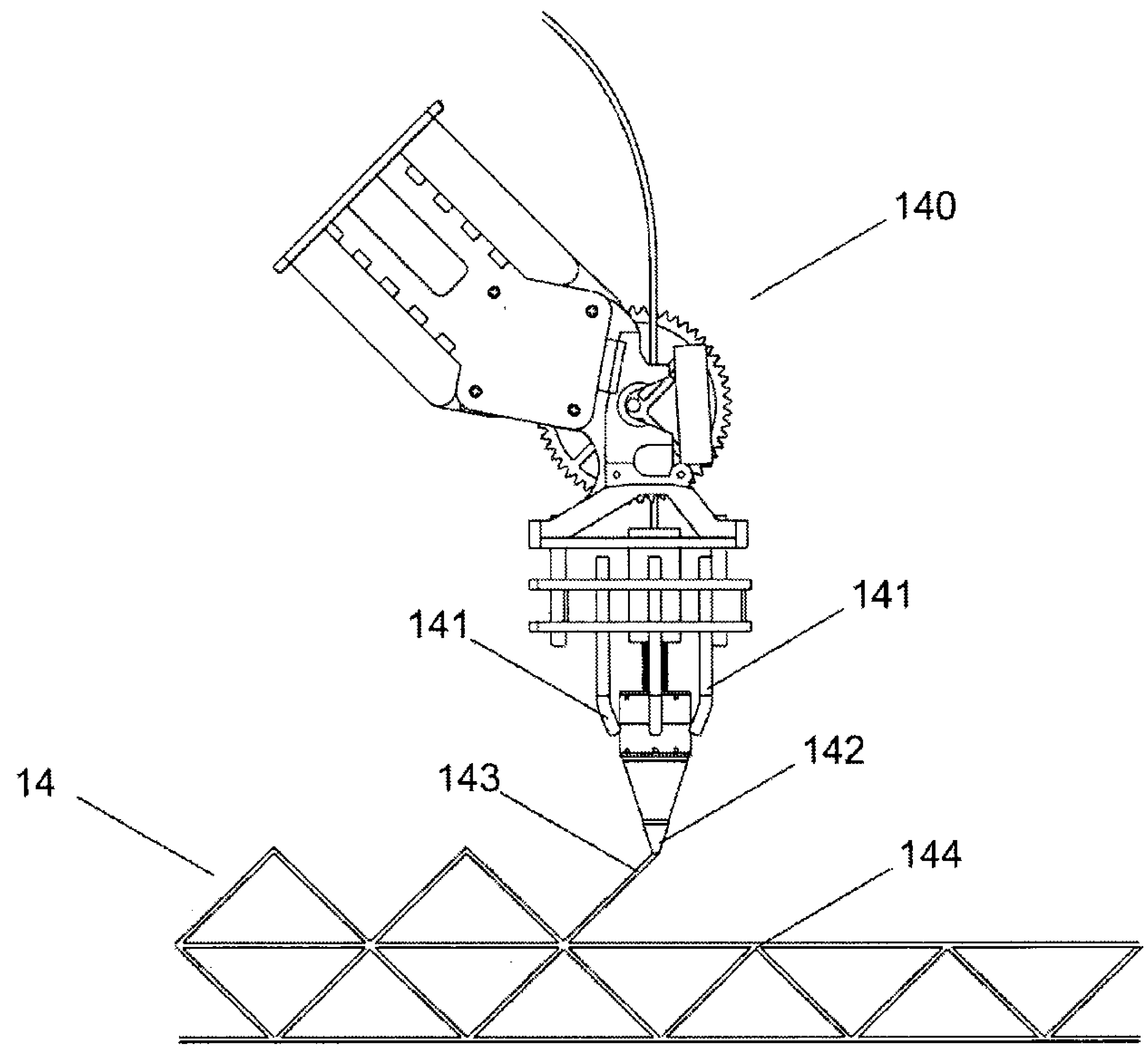

Fig. 23

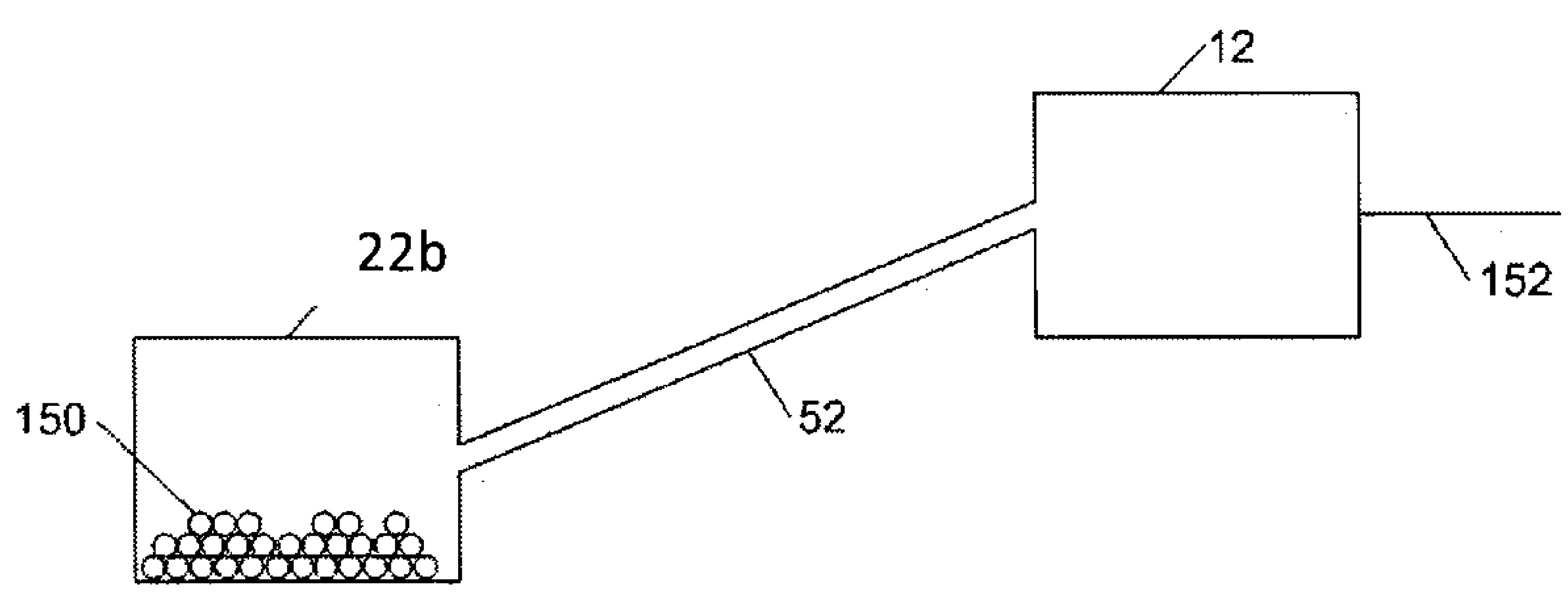

Fig. 24

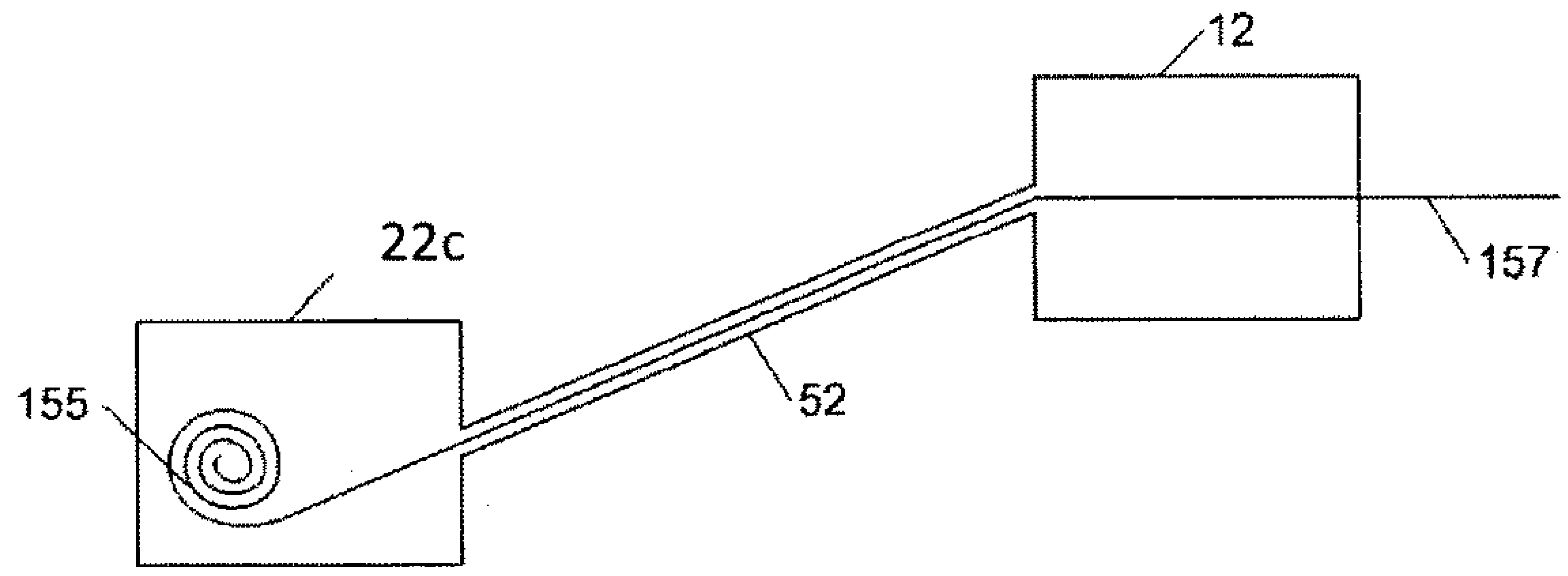
12
22c
157
155
52

Fig. 25

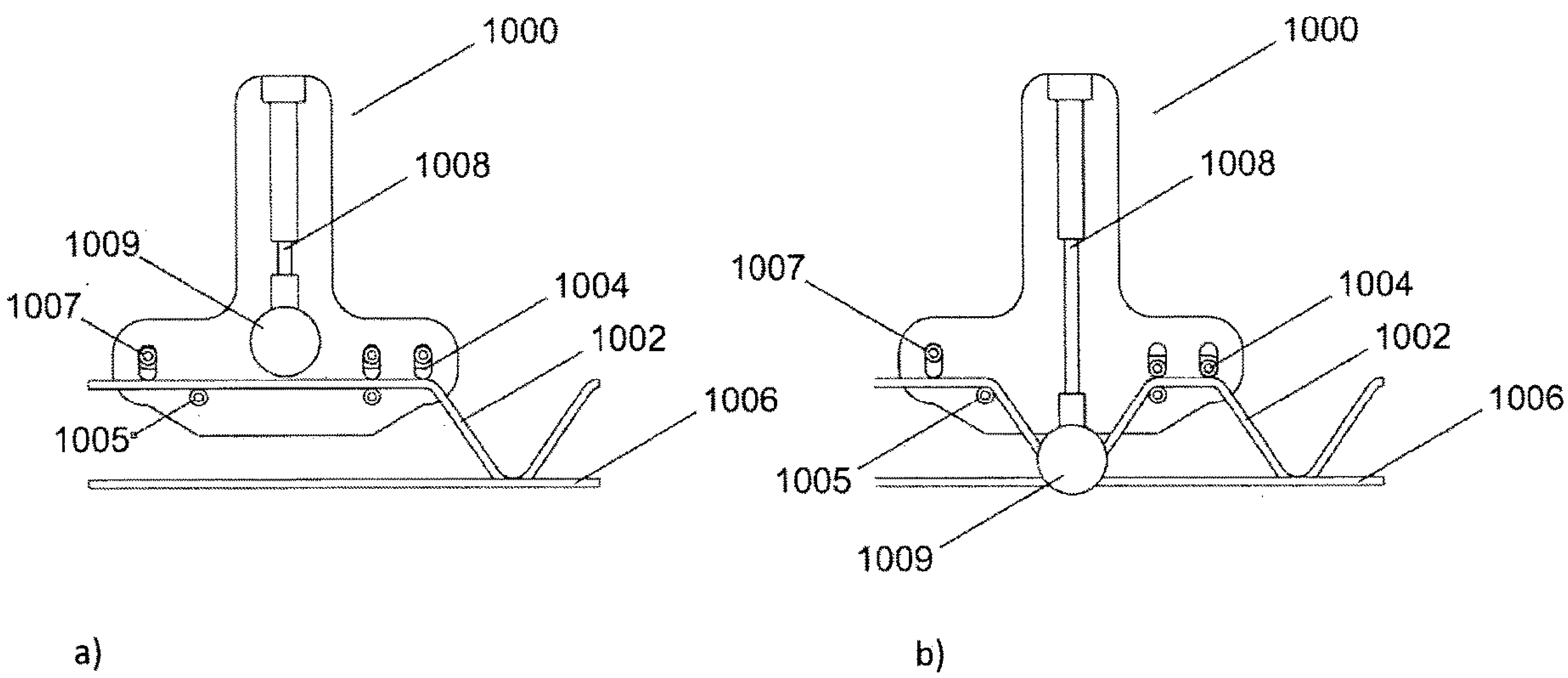
1000
1008
1009
1007
1004
1002
1006
1005
a)
1000
1008
1007
1004
1002
1006
1005
1009
b)

Fig. 26

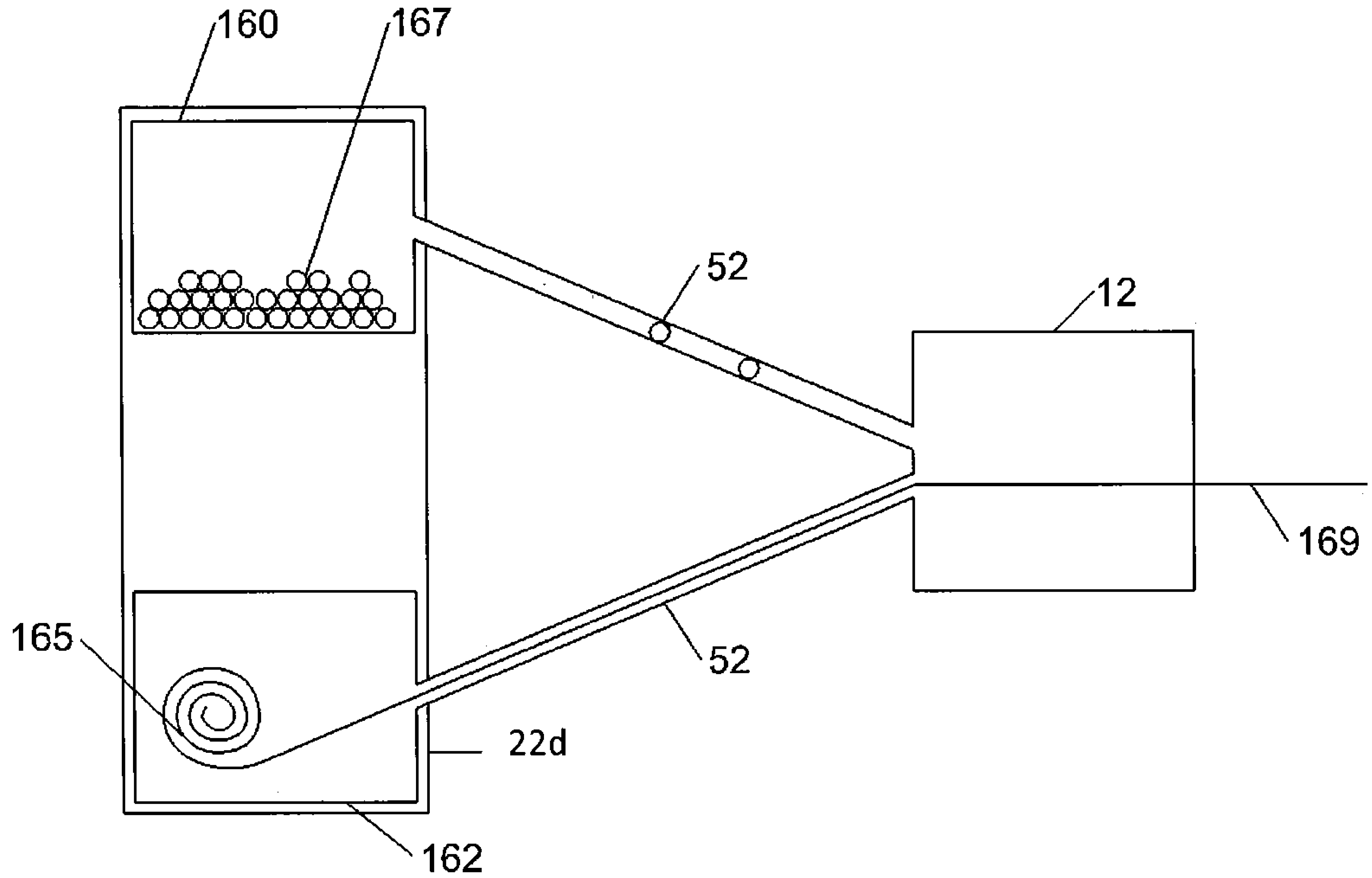
160
167
52
12
169
165
52
22d
162

Fig. 27

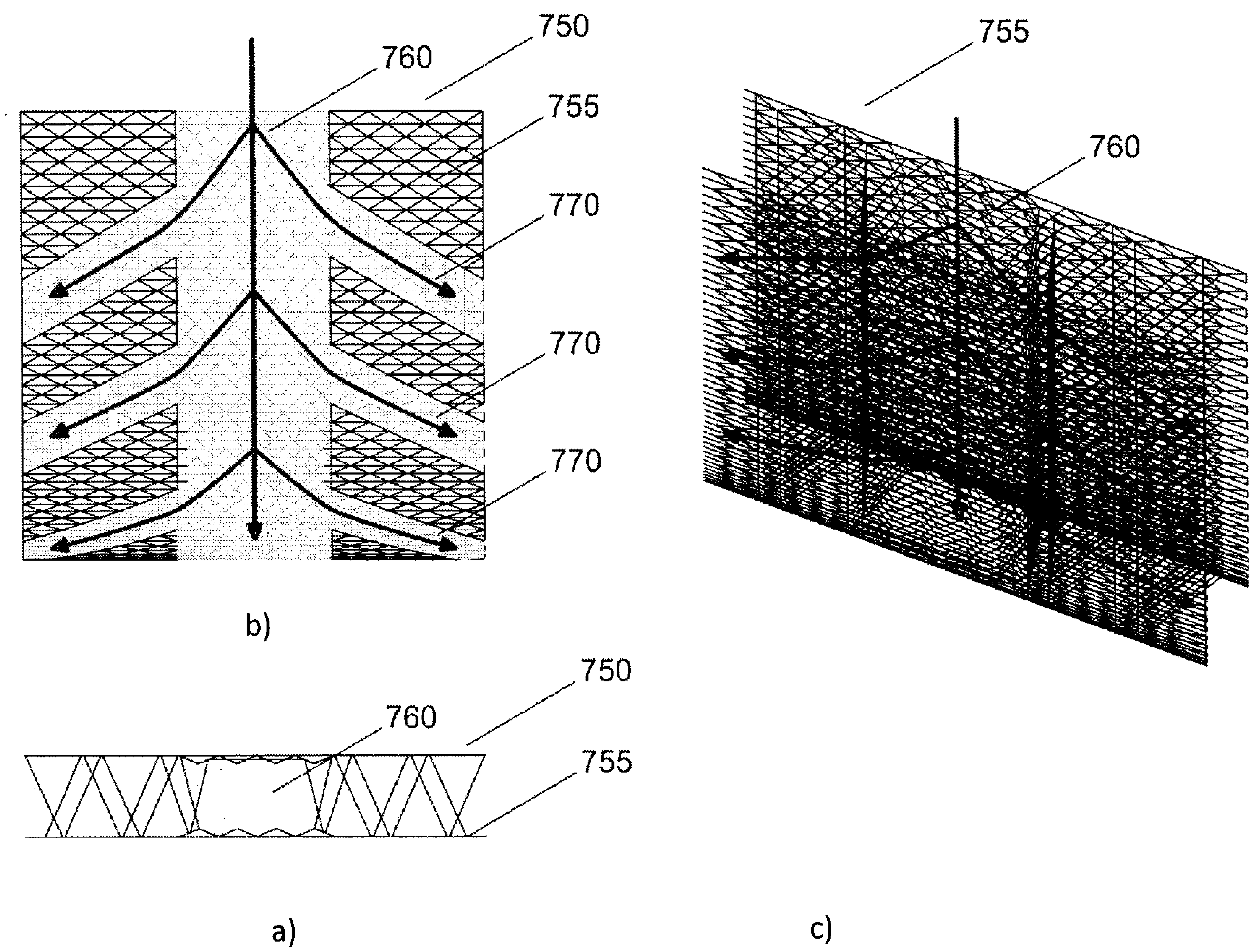
750
760
755
770
770
770
b)
750
760
755
a)
755
760
c)

Fig. 28

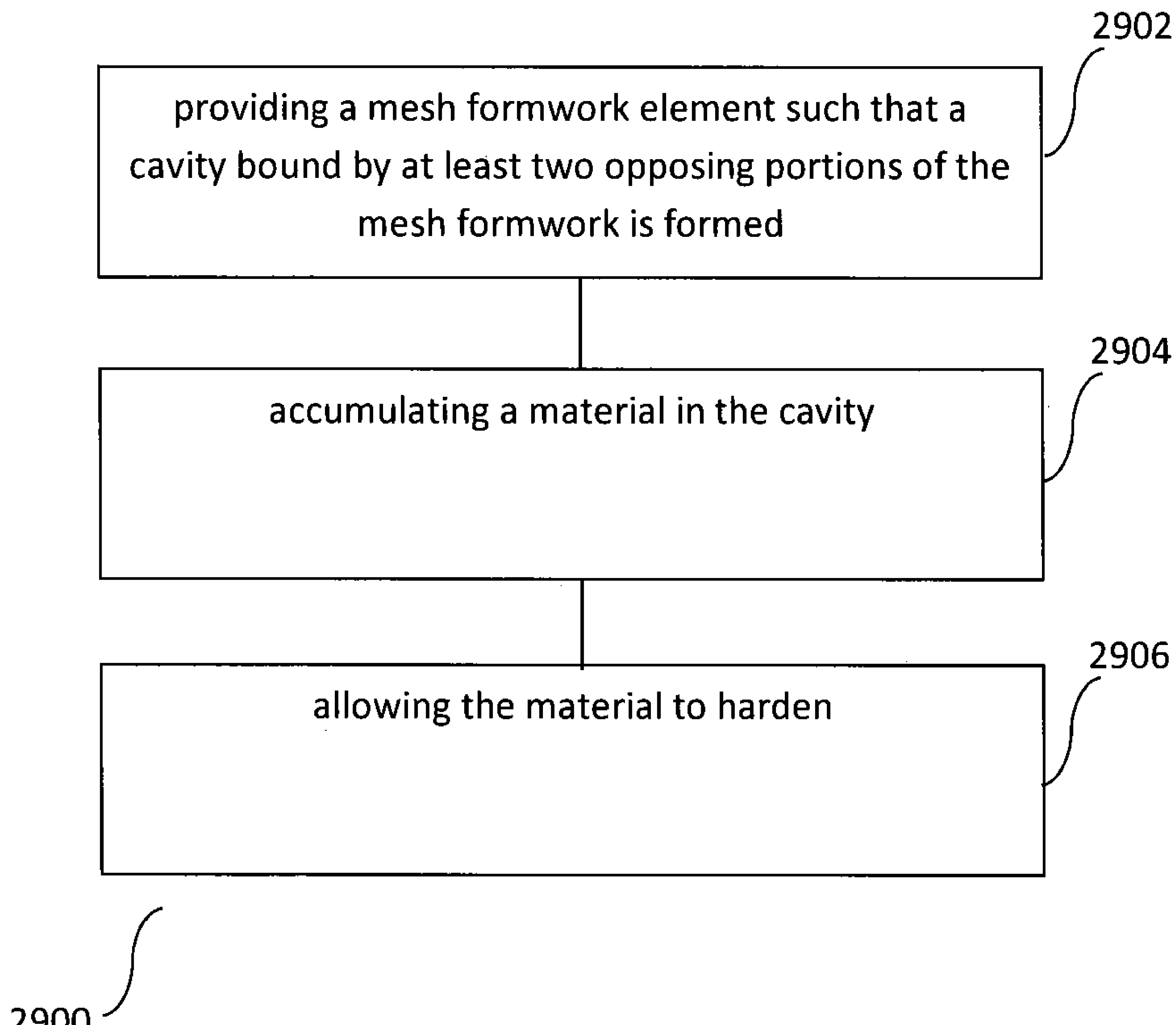
2902
providing a mesh formwork element such that a cavity bound by at least two opposing portions of the mesh formwork is formed
2904
accumulating a material in the cavity
2906
allowing the material to harden
2900

Fig. 29

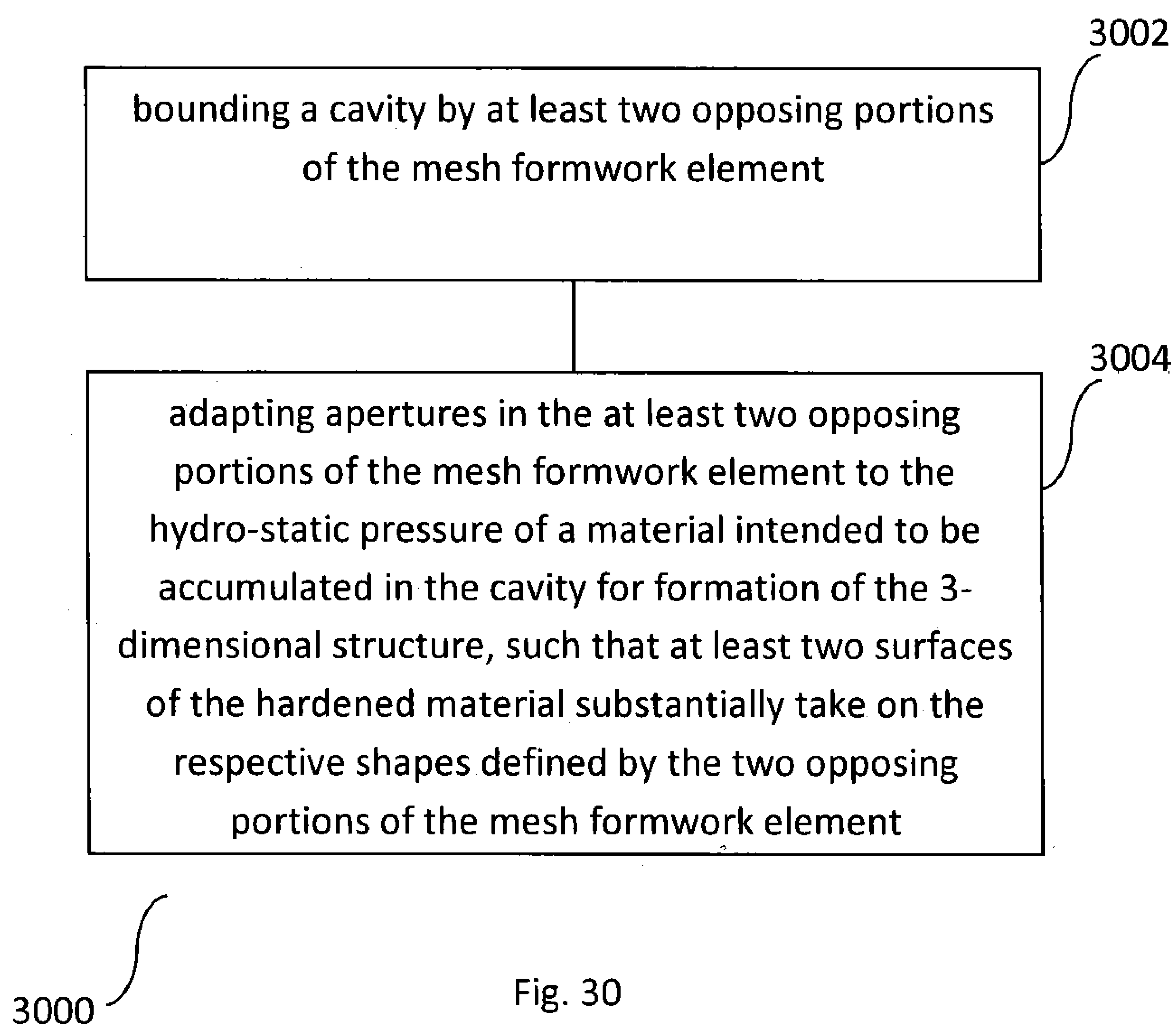
3002
bounding a cavity by at least two opposing portions of the mesh formwork element
3004
adapting apertures in the at least two opposing portions of the mesh formwork element to the hydro-static pressure of a material intended to be accumulated in the cavity for formation of the 3-dimensional structure, such that at least two surfaces of the hardened material substantially take on the respective shapes defined by the two opposing portions of the mesh formwork element
3000

Fig. 30

METHOD OF FABRICATING A 3-DIMENSIONAL STRUCTURE, MESH FORMWORK ELEMENT FOR FABRICATING A 3-DIMENSIONAL STRUCTURE AND METHOD OF FABRICATING THE SAME

FIELD OF INVENTION

This application relates broadly to a method of fabricating a 3-dimensional structure, a mesh formwork element for fabricating a 3-dimensional structure, and a method of fabricating the same.

BACKGROUND

DE20 2004 006 662 U1 shows a three-dimensional moulded wire fabric comprising loops with different sizes knitted together by at least the two previous loops. Individual wires are mechanically fixed together on the crossing points or contact points on pre-determined sites.

WO 2003029573 A1 discloses a hollow formwork for a reinforcing concrete structure, such as a concrete floor. The formwork comprises a hollow tube having a circular, square, trapezoid, or other shape. A transversely stiffening rib is fixed to the inside of the hollow tube in a direction perpendicular to the axis thereof. A reinforcing bar, which is formed on the two sides of the transversely stiffening rib, may be extended beyond the hollow tube. The reinforcing bar is extended outside the tube to form an reinforcing bar.

EP 1321602 A1 discloses a formwork apparatus for forming a concrete structure. The formwork apparatus comprises at least one formwork shuttering-panel and a forming element, such as a boot movably mounted relative to the shuttering panel. A forming element is supported by an arm, which in turn is supported by a clamp that is removably attached to upper edge of the shuttering panel.

At least preferred embodiments of the present invention seek to provide an improved method of fabricating a 3-dimensional structure, mesh formwork element for fabricating a 3-dimensional structure, and method of fabricating the same.

SUMMARY

In accordance with a first aspect of the present invention there is provided a method of fabricating a 3-dimensional structure, the method comprising providing a mesh formwork element such that a cavity bound by at least two opposing portions of the mesh formwork is formed; accumulating a material in the cavity; and allowing the material to harden; wherein apertures in the at least two opposing portions of the mesh formwork element are adapted to the hydro-static pressure of the accumulated material or vice versa such that at least two surfaces of the hardened material substantially take on the respective shapes defined by the two opposing portions of the mesh formwork element.

In accordance with a second aspect of the present invention there is provided a mesh formwork element for fabricating a 3-dimensional structure, comprising a cavity bound by at least two opposing portions of the mesh formwork element; wherein apertures in the at least two opposing portions of the mesh formwork element are adapted to the hydro-static pressure of a material intended to be accumulated in the cavity for formation of the 3-dimensional structure, such that at least two surfaces of the hardened material substantially take on the respective shapes defined by the two opposing portions of the mesh formwork element.

In accordance with a third aspect of the present invention there is provided a mesh formwork structure comprising a plurality of mesh formwork elements as defined in the second aspect.

In accordance with a fourth aspect of the present invention there is provided a 3-dimensional structure comprising one or more formwork elements as defined in the second aspect.

In accordance with a fifth aspect of the present invention there is provided a method of fabricating a formwork element for fabricating a 3-dimensional structure, the method comprising bounding a cavity by at least two opposing portions of the mesh formwork element; and adapting apertures in the at least two opposing portions of the mesh formwork element to the hydro-static pressure of a material intended to be accumulated in the cavity for formation of the 3-dimensional structure, such that at least two surfaces of the hardened material substantially take on the respective shapes defined by the two opposing portions of the mesh formwork element.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

FIG. **1** illustrates a perspective view of a movable robot and a fabricated mesh formwork,

FIG. **2** illustrates a side cross-sectional view of the fabricated mesh formwork of FIG. **1**,

FIG. **3** illustrates another side cross-sectional view of the fabricated mesh formwork of FIG. **1**,

FIG. **4** illustrates a top view of a part of the fabricated mesh formwork of FIG. **1**,

FIG. **5** illustrates an expanded view of a portion of the fabricated mesh formwork of FIG. **4**,

FIG. **6** illustrates a cross-sectional view of a joint of two filaments for an extruded mesh formwork of FIG. **1**,

FIG. **7** illustrates a cross-sectional view of a filament that is extruded from an extruder head of the robot of FIG. **1** along a longitudinal axis of the extruder head,

FIG. **8** illustrates a cross-sectional view of a filament that is extruded from the extruder head of the robot of FIG. **1** along a lateral axis of the extruder head,

FIG. **9** illustrates a cross-sectional view of a filament that is extruded diagonally from the extruder head of the robot of FIG. **1**,

FIG. **10** illustrates a force locking of two filaments for an extruded mesh formwork of FIG. **1**,

FIG. **11** illustrates the force locking of FIG. **12** with a further filament,

FIG. **12** illustrates a side view of a device for a further force locking of filaments for an extruded mesh formwork of FIG. **1**,

FIG. **13** illustrates another side view of a further force locking of filaments using the device of FIG. **12**,

FIG. **14** illustrating a roughing of a filament for the mesh formwork of FIG. **1**,

FIG. **15** illustrates a cross-sectional view of a filament that comprises a bundle of steel wires filament and a coating for the mesh formwork of FIG. **1**, FIG. **16** illustrates filling the mesh formwork of FIG. **1** with a cementitious mixture by spraying for fabricating a concrete structure,

FIG. **17** illustrates filling the mesh formwork of FIG. **1** with a cementitious mixture by pouring for fabricating a concrete structure,

FIG. **18** illustrates a reinforced formwork fabricated by the robot of FIG. **1**,

FIG. **19** illustrates a further reinforced formwork fabricated by the robot of FIG. **1**,

FIG. **20** illustrates another reinforced formwork fabricated by the robot of FIG. **1**,

FIG. **21** illustrates a further fabricated mesh formwork with different apertures at different heights,

FIG. **22** illustrates one implementation of the material container of the robot of FIG. **1**,

FIG. **23** illustrates one implementation of an end-effector of the robot of FIG. **1** in the form of an extruder head and use thereof to fabricate a reinforced formwork,

FIG. **24** illustrates a further implementation of the material container of the robot of FIG. **1**,

FIG. **25** illustrates another implementation of the material container of the robot of FIG. **1**,

FIG. **26** illustrates one implementation of an end-effector of the robot of FIG. **1** in the form of a bending and welding head and use thereof to fabricate a reinforced formwork,

FIG. **27** illustrates another implementation of the material container of the robot of FIG. **1**,

FIG. **28** illustrates a cross-sectional view of a fabricated mesh formwork with channels for receiving a fresh cementitious mixture,

FIG. **29** illustrates a flowchart for fabricating a 3-dimensional structure, according to an example embodiment, and

FIG. **30** illustrates a flowchart for fabricating a formwork element for fabricating a 3-dimensional structure, according to an example.

DETAILED DESCRIPTION

In the following descriptions, details are provided to further explain embodiments of possible applications. It shall be apparent to one skilled in the art, however, that the embodiments may be practiced without such details.

Some parts of the embodiments, which are shown in the Figs., have similar parts. The similar parts have the same names or similar part numbers with a prime symbol or with an alphabetic symbol. The description of such similar parts also applies by reference to other similar parts, where appropriate, thereby reducing repetition of text without limiting the disclosure.

FIG. **1** shows a movable robot **10** and an extruded mesh formwork **14** that is extruded by the robot **10**.

The mesh formwork **14** has a cavity **59** bound by two opposing portions **61**, **63** of the mesh formwork **14**. In the mesh formwork **14**, the side portions **65**, **67** of the mesh formwork **14** also bound the cavity **59**. It is noted that in different embodiments, aperture-less elements, such as panels or sheets may be provided at the sides of a mesh formwork made up by the two opposing portions **61**, **63**.

The apertures e.g. **55**, **57** of the mesh formwork **14** are adapted to the hydro-static pressure of a material which is accumulated in the cavity to fabricate a 3-dimensional structure. Alternative, the hydro-static pressure of a material which is accumulated in the cavity to fabricate a 3-dimensional structure is adapted apertures e.g. **55**, **57** of the mesh formwork **14**.

After hardening, surfaces of the hardened material substantially take on the respective shapes defined by the portions of the mesh formwork element, thus a 3-dimensional structure can be fabricated that substantially takes its shape from the shape of the mesh formwork.

Advantageously, the material, such as a fresh cementitious mixture, protrudes through the apertures during hardening so as to embed the mesh formwork **14** such that the mesh formwork **14** re-enforces the fabricated structure, e.g. a concrete structure.

The robot **10** can produce different mesh formworks **14** with various shapes made from a filament/wire or filaments/wires. The robot **10** is controlled by a program, which provides different instructions for producing different mesh formworks **14**. These fabricated mesh formworks **14** can have one or more curved surfaces and one or more flat surfaces. In other words, the shape of the mesh formwork **14** can be complex. This is unlike other formwork techniques where the formwork has mainly planar surfaces which limits the shapes of the structures that can be constructed.

The movable robot **10** has an adjustable and mobile base or main body **20**, with a material container **22** as well as an arm unit **25** with an end-effector **12**.

In particular, the arm unit **25** is attached to an upper surface of the main body **20**. The end-effector **12** is attached to a distal end of the arm unit **25**. The material container **22** is placed above the main body **20**. In other words, the extruding container **22** is located in the vicinity of the main body **20**.

The main body **20** includes a pair of moving means **30**. Each movement means **30** includes a continuous Caterpillar track **32**. The moving means **30** are attached to a lower surface of the main body **20**. As seen in FIG. **1** the continuous tracks **32** extend from one end to another end of the main body **20**. The main body **20** has track-driving pulleys, which engages with the continuous tracks **32**. The track-driving pulleys are not shown in the FIG. **1**.

The main body **20** also includes an outrigger unit **35** that is attached to sides of the main body **20**. The outrigger unit **35** comprises horizontal beams **37** and vertical poles **39** that attached to outer ends of the horizontal beams **37** as well as a hydraulic means that is attached to horizontal beams **37** and the vertical poles **39**. The hydraulic means is not shown in the FIG. **1**.

The arm unit **25** includes a first link **41** and a second link **43**. As seen in FIG. **1**, the first link **41** has a first end and a second end. The first end is attached to an arm rotatable means **27** by a rotatable body joint **45**, wherein the arm rotatable means **27** is attached to an upper surface of the main body **20**. The first link **41** is attached to a first link driving mechanism that is not shown in FIG. **1**.

Similarly, the second link **43** has a first end and a second end. The first end is attached to the second end of the first link **41** by a rotatable link joint **47** while the second end is attached to the end-effector **12**. The second link **43** is also attached to a second link driving mechanism that is not shown in the FIG. **1**.

The end-effector **12** includes a controller, a camera unit, and an extruding nozzle **50**. The controller and the camera unit are not shown in the Figs.

The material container **22** is located in the vicinity of the main body **20**. Pipes **52** connect the material container **22** to the end-effector **12**.

In a generic sense, wheels or a rolling platform can replace the tracks **32**.

The track-driving pulleys turn the Caterpillar tracks **32** for moving the main body **20** to desired positions.

The outrigger unit **35** keeps the main body **20** stable, especially when the arm unit **25** is in motion. In detail, the hydraulic means moves the horizontal beams **37** and the vertical poles **39** such that the main body **20** and the moving means **30** are lifted off the ground to keep the main body **20** from shifting and swinging.

The arm rotatable means **25** rotates about a vertical axis for revolving the arm unit **25**.

The first link driving mechanism positions the first link **41** at different angles with respect to the main body **20**. Likewise, the second link driving mechanism positions the second link **43** at different angles with respect to the first link **41**.

The material container **22** holds a material for transferring to the end-effector **12**.

The location of the material container **22** provides an advantage in that this allows the end-effector **12** to receive material from the said container **22** while not bearing the weight of the said container **22**. Because of this, the end-effector **12** is lighter and is easier to position.

The pipes **52** provide a passageway for channelling extruding material from the material container **22** to the end-effector **12**. Referring to the end-effector **12**, the camera unit receives images around the end-effector **12** and sends these images to the controller, wherein the controller checks tolerances of the produced mesh to position accurately the extruding nozzle **50**.

In a general sense, a sensor, such as an optical sensor, a surface tension sensor, a temperature sensor, or a sonic sensor, can replace the camera unit.

The nozzle **50** receives the material from the material container **22**. The extruding nozzle **50** then expels these materials to form elongated filament sections for fabricating the mesh formwork **14**.

One implementation of the material container **22** is shown in FIG. **22**. FIG. **22** shows a material container **22***a* that holds a reel of elongated Kevlar, basalt, glass fibre or such wire **155** that is coated with plastic material. The pipe **52** provides a passageway for transferring the plastic coated wire **155** to the end-effector **12**. The end-effector **12** then heats the plastic coated wire **155** such that its plastic coating is mouldable. The end-effector **12** then expels the heated plastic coated wire **155** to form an elongated filament **157**. The filament **157** comprises the wire **155** and a plastic coating. The plastic coating surrounds or encloses the wire **155** such that the plastic coating is essentially fixed to the wire **155**. The wire **155** serves as a core of the filament **157**. The plastic coating of the filament **157** is formed from the plastic coating of the wire **155**. The extruded filament **157** is hot, thereby allowing the extruded filament **157** sections to stick to other filament sections with a plastic outer surface.

In a generic sense, a bamboo strand, a Kevlar wire, a carbon wire, a glass fibre wire, a basalt wire, or other natural fibres like hemp fibres can be used as the wire **155**.

In application, the extruded filament **157** with the wire core **155** that is surrounded with a plastic coating provides rigidity and strength to the mesh formwork **14**, such that mesh formwork **14** is able to hold a fresh cementitious mixture. Furthermore, the wire **155** of the filament **157** provides good tensional strength. In short, after curing, the coated wire mesh formwork **14** acts as reinforcement.

FIG. **23** shows details of one implementation of the end-effector **12**, in the form of an extruder head **140**. In application, the extruded filament **143**, which can comprise polymers or polymer coated/coextruded filaments, is used to fabricate a rigid and strong mesh formwork **14**, such that the mesh formwork **14** is able to hold a material such as a wet, liquid, or viscous cementitious mixture. The wet, liquid, or viscous cementitious mixture is also called a fresh cementitious mixture. Furthermore, the filament **143** provides good tensional strength to the mesh formwork **14**. In short, after curing of the material, for example of the fresh cementitious mixture, the wire mesh formwork **14** acts as reinforcement for the fabricated 3-dimensional structure. FIG. **23** shows the extruder head **140** which in this embodiment comprises cooling air ducts e.g. **141** for directing respective cooling air jets (not shown) to the exit tip **142** of the extruder head, for hardening the extruded filament **143** upon exit from the tip **142**, thus providing the mesh formwork **14**. As will be appreciated by a person skilled in the art, in regions e.g. **144** where freshly extruded filament **143** sections contact previously extruded sections, a strong joint is formed during the cooling of the freshly extruded sections.

Another implementation of the material container **22** is shown in FIG. **24**. FIG. **24** shows a material container **22***b* that holds an extruding material that comprises a plurality of plastic granules **150**. The pipe **52** provides a passageway that allows transfers of the plastic granules **150** to the end-effector **12**. The end-effector **12** later heats the plastic granules **150** such that the plastic granules are mouldable. The end-effector **12** afterward expels the plastic granules **150** to form an elongated plastic filament **152**. The extruded plastic filament **152** is hot such that it can stick or adhere to other filament with a plastic other surface.

In a general sense, instead of the plastic granules **150**, a plurality of plastic sticks or a reel of plastic stick can also be used to produce the plastic filament **152**.

In a special embodiment, the extruding material container **22** is mobile for supplying material to the end-effector **12** while not taking limited space such that the robot **10** can have more space for manoeuvring.

In practice, the extruded plastic filament **152** provides rigidity and strength to the mesh formwork **14**, such that mesh formwork **14** is able to hold a fresh cementitious mixture.

Another implementation of the material container **22** is shown in FIG. **25**. FIG. **25** shows a material container **22***c* that holds a reel of elongated metal wire **155**. The pipe **52** provides a passageway for transferring the metal wire **155** to the end-effector **12**. The end-effector **12** expels a filament **157** with a desired cross-sectional size and/shape. The 3-dimensional position of the end-effector **12** is varied to form the mesh formwork **14** (see FIG. **1**).

FIGS. **26***a*) and *b*) show details of one implementation of the end-effector **12** in the form of a bending and welding head **1000**. In application, for example a metal filament in the form of a suitably sized and shaped metal wire **1002**, which may be directly supplied from a reel (not shown) is used to fabricate a rigid and strong mesh formwork **14**, such that the mesh formwork **14** is able to hold a material such as a wet, liquid, or viscous cementitious mixture. The wet, liquid, or viscous cementitious mixture is also called a fresh cementitious mixture. Furthermore, the metal wire **1002** provides good tensional strength to the mesh formwork **14**. In short, the wire **1002** is fed through guides e.g. **1004**, **1005**, **1007** of the moving head **1000**. For forming a joint to a previously laid wire section **1006**, a linear actuator **1008** is moved downward, thus deforming or bending the wire **1002** between the guides e.g. **1004**, **1005**, **1007**, as shown in FIG. **26***b*. During the bending and welding, moveable ones of the guides e.g. **1004** move to grip the metal wire **1002**, to hold it in place. In this embodiment, guide **1007** remains "open" so as to enable feeding of metal wire **1002** to accommodate the bending.

When the linear actuator **1008** has reached a position in which a section of the wire **1002** contacts the previously laid wire section **1006**, a welding voltage/current is applied via a welding electrode **1009**, for forming a joint.

A further implementation of the material container **22** is shown in FIG. **27**. FIG. **27** shows a material container **22***d* that includes a coating material container **160** and a load-bearing element material container **162**.

The load-bearing element material container **162** holds a reel of wire **165** with good tensional strength. The pipe **52** connects the load-bearing element material container **162** thereby allowing the basalt, Kevlar, glass fiber or such wire **165** to reach the end-effector **12**.

The coating material container **160** holds a plurality of plastic granules **167**. The pipe **52** provides a passageway that allows transfers of the plastic granule **167** to the end-effector **12**. The end-effector **12** then heats the transferred plastic granules **167** such that the plastic granules **167** are mouldable.

The end-effector **12** afterward expels the wire **165** and the mouldable plastic granules **167** to form a filament **169** such that the filament **169** comprises a core that includes the wire **165**, wherein the core is coated with plastic. The plastic coat, which surrounds the core, is formed from the mouldable plastic granules **167**.

Operationally, the extruded filament **169** provides rigidity and strength to the mesh formwork **14**, wherein the mesh formwork **14** is able to hold a fresh cementitious mixture. The wire **167** provides good tensional strength to the mesh formwork **14** while the plastic coating facilitates joint forming.

Returning to FIG. **1**, the mesh formwork **14** is used for receiving a material such as wet or fresh cementitious mixture, which has a predetermined viscosity, in the cavity **59**. The mesh formwork **14** then shapes the cementitious mixture and holds the fresh cementitious mixture.

As mentioned above, the dimensions of the apertures **55**, **57** are adapted to the hydrostatic pressure of e.g. a liquid cementitious mixture such that the apertures **55**, **57** hold the fresh cementitious mixture. The arrangement of the filament or filaments from which the mesh formwork **14** is fabricated also provides rigidity to the mesh formwork **14** and also facilitates adherence of the cementitious mixture to the mesh formwork **14** Only a small portion of the fresh cementitious mixture flows through the apertures **55**, **57** at a predetermined flow rate. This small portion of the fresh cementitious mixture forms the outer surface of the cementitious mixture.

Later the cementitious mixture sets and hardens to form the desired concrete structure. The finished concrete structure has essentially the shape of the mesh formwork **14**.

The outer surface of the hardened cementitious mixture can then be smoothed by trowelling or the like, and, if desired, the outer surface can be finished simply by painting or by application of an acrylic render, cementitious render, mortar, and other finishes are also possible.

As apparent from the above description, the mesh formwork **14** is embedded in the cementitious mixture. This is an advantage, as the mesh formwork **14** need not be removed from the concrete structure. This is different from other formworks, wherein the other formworks are removed from the finished concrete structure and are then discarded or reused after big efforts for cleaning lumps of cementitious mixture off these formworks. Furthermore, the mesh formwork **14** can comprise material that allows the mesh formwork **14** to have good tensional strength. Such a tensile-active formwork can provide a benefit to concrete structures. For example, concrete structures generally have good compressive strength and poor tensional strength. When these concrete structures are embedded with this formwork **14**, these concrete structures have both good compressive strength and good tensional strength in that the tensile active formwork takes up the tensional stresses of the hardened concrete structure.

This formwork **14** can also replace or reduce reinforcement bars, which are typically embedded in the fresh cementitious mixture. The shape of the formwork **14** can be adjusted to various loads, which allows saving of construction material.

FIGS. **2** to **5** show different views of the mesh formwork **14**.

The mesh formwork **14** includes a plurality of straight filament sections and a plurality of connecting filament sections, wherein the connecting filaments are attached to the straight filaments.

In particular, the mesh formwork **14** includes a first structure and a second structure of filaments. The first structure and the second structure have similar parts and are arranged in a similar manner.

As seen in FIGS. **2** and **3**, the first structure has a plurality of first straight filament sections **201'**, **203'**, and **206'** and a plurality of first connecting filament sections **202'** and **205'**. The first straight filament sections **201'**, **203'**, and **206'** are placed in a first XZ plane. The first straight filament section **203'** is placed above the first straight filament section **201'** while the first straight filament section **206'** is placed above the first straight filament section **203'**.

The first connecting filament section **202'** connects to the first straight filament section **201'** and to the first straight filament section **203'**. The first connecting filament section **202'** has essentially a shape of a sine curve. The sine curve has peaks and troughs. The peaks and troughs are also called turning areas **501**, **502**, **503**, **504**, **505**, and **506**. These turning areas **504** and **506** are connected to the first straight filament section **201'** while the turning area **505** is connected to the first straight filament section **203'**.

In a manner similar to the above, the first connecting filament section **205'** connects to the first straight filament section **203'** and to the first straight filament **206'**.

Referring to the second structure, it includes a plurality of second straight filament sections **201**, **203**, and **206** and a plurality of second connecting filament sections **202** and **205**.

These filament sections of the second structure are arranged in a manner similar to the filament sections of the first structure.

The mesh formwork **14** also includes cross connecting filament sections **204** and **207**.

As seen in FIG. **4**, the cross connecting filament section **204** has a shape of a sine curve. Turning areas **512** and **516** of the sine curve are attached to the first straight filament section **203'** while turning areas **510** and **514** are connected to the second straight filament section **203**.

Similarly, as seen in FIG. **2**, the cross connecting filament section **207** is attached to the first straight filament section **206'** and to the second straight filament section **206**.

FIG. **5** shows a joint between the second connecting filament section **204** and the second straight filament section **203**.

The turning area **510** of the second connecting filament section **204** is attached to a portion of the second straight filament section **203**. The turning area **510** has a first portion with a width d**1**, a second portion with a width d**2**, and a turning portion with a width d**3**. The first portion is integrally connected to the second portion while the second portion is integrally connected to the turning portion.

The width d**1** is less than the width d**2** while the width d**2** is less than the width d**3**. These widths d**1**, d**2**, and d**3** are different because the second filament section **204** is formed by extrusion at different speeds and at different angles. In other words, the different widths d**1**, d**2**, and d**3** are marks or characteristics of the extrusion process.

FIG. **6** shows a cross-sectional view of a further joint of two extruded filament section s **301** and **302** for the mesh formwork **14**.

The two filament sections **301** and **302** have an elongated cylindrical shape with an essentially round cross-section. The filament sections **301** and **302** are produced by extrusion using a polymer. The two filament sections **301** and **302** are placed at a pre-determined angle with respect to each other. Portions of the filament sections **301** and **302**, which are jointed to each other have a flatten shape. The shape of the joint is a mark or characteristic of the extrusion process.

FIG. **7** shows a cross-sectional view of a filament section **208** that is extruded by the extruder head **170** in a longitudinal direction of the filament section **208**.

The filament section **208** has an elongated cylindrical core **62** and an elongated tubular coating **63** that surrounds the core **62**. The core **62** has an essentially constant cross-section while the coating **63** has different external diameters D at different areas of the coating **63**.

While extruding the filament section **208**, the extruder head **170** is moving with velocity Vz in the longitudinal direction of the filament section **208**, as indicated by an arrow in FIG. **7**. The velocity Vz changes over time. Because of this, the external diameters D of the coating **63** are different at different areas of the coating **63**. These different external diameters D are characteristics or marks of the changing velocity Vz of the extrusion process of the filament section **208**.

FIG. **8** shows a cross-sectional view of another filament section **209** that is extruded by the extruder head **170** in a lateral direction of the filament **209**.

The filament section **209** has an elongated cylindrical core **66** and an elongated tubular coating **68** that surrounds the core **66**. The core **66** has an essentially constant cross-section while the coating **68** has protrusions **64** on an inner surface **70** of the coating **68** and gentle irregularities on an outer surface **72** of the coating **68**. The inner surface **70** is opposite to the outer surface **72**.

During the extrusion of the filament section **209**, the extruder head **170** is moving with velocity Vx in the lateral direction of the filament section **208**, as indicated by an arrow in FIG. **7**. The velocity Vx changes over time. These protrusions **64** are marks or characteristics of the changing velocity Vx of the extrusion process of the filament section **209**.

FIG. **9** shows a cross-sectional view of a further filament section **210** that is extruded diagonally from the extruder head **170** in a lateral direction of the filament section **210**, as indicated by an arrow in FIG. **9**.

The filament section **210** has an elongated cylindrical core **75** and an elongated tubular coating **77** that surrounds the core **75**. The core **75** has an essentially constant cross-section while the coating **77** has protrusions **78** on one side of the coating **77**.

When extruding the filament section **210**, the extruder head **170** is moving with velocity Vx in the lateral direction and with velocity Vz in the longitudinal direction of the filament section **210**, as indicated by an arrow in FIG. **9**. The velocities Vx and Vz change over time. These protrusions **78** are marks or characteristics of changing velocities Vx and Vz of the extrusion process of the filament section **210**.

Different means of force locking one filament section to another filament section are possible.

FIGS. **10** to **11** show a force locking **90** of filament sections via a knot for the mesh formwork **14**. The knot refers to parts of the filament section that are tied or twisted together to form a lump for fastening or tying together.

FIG. **10** shows a force locking **90** of an extruded first filament section **215** with an extruded second filament section **216**. The first filament section **215** has a loop **92** with a partly open curve.

A first connecting part integrally attaches one end of the partly open curve to one end of a first straight filament element **94**. A second connecting part integrally attaches another end of the partly open curve to one end of a second straight filament element **96**. Referring to the second filament section **216**, it loops around the first and the second connecting parts.

FIG. **11** shows a third filament section **217** passing through the loop **92**. FIG. **11** also shows shearing forces of the first and the second filament sections **215** and **216**.

These shearing forces can be present when the first, the second, and the third filament sections **215**, **216**, and **217** are embedded in a cementitious mixture and when tensional forces are applied to the cementitious mixture. The tensional forces extend the first filament section **215** and the second filament section **216** such that these filament sections **215** and **216** are subjected to the shearing forces. The loop **92** later tightens around the third filament section **217**.

In summary, FIGS. **9** to **10** show a pseudo weaving of a mesh formwork.

FIG. **12** shows a side view of a filament device **106** for a further force locking of filament sections for the extruded mesh formwork **14**. The device includes a straight filament section **99**, wherein end portions of the straight filament section **99** are connected to filament discs **103**.

FIG. **13** shows another side view of a further force locking of filament sections using the device **106**. FIG. **13** shows a first filament section **98** looping over the straight filament section **99** and contacting with the straight filament section **99** from one direction and a second filament section **101** looping over and contacting with the straight filament section **99** from an opposite direction.

FIG. **14** shows a roughing of a filament for the extruded mesh formwork **14**. FIG. **14** shows a nozzle **102** spraying sand **103** over a surface of a filament section **104**. The surface of the filament section **104** is made from plastic and is also hot and mouldable such that the sand **103** sticks to the surface. When cooled, the surface of the filament section **104** is roughened for connecting with a cementitious mixture that surrounds the filament section **104** in a form-fitting manner.

FIG. **15** shows a further extruded filament **223** for the mesh formwork **14**. The filament section **223** comprises an extruded bundle of wires **110** and an extruded polymer coating **112** that surrounds the wires **110**. The bundle of wires **110** provides extended mechanical strength. In a general sense, fibres can replace the wires **110**. The wires **110** or fibres may comprise, for example, bamboo strand, Kevlar wire, carbon wire, glass fibre wire, basalt wire, or other natural fibres like hemp fibres.

Different ways of using the mesh formwork are possible.

FIG. **16** shows an extruded mesh formwork **115** being sprayed with cementitious mixture, in the form of Shotcrete in an example embodiment, from a hose **120** from a distance d of, for example, at least 30 centimetres (cm).

The formwork **115** comprises a plurality of filaments in which the filaments define apertures. The filaments are not shown in FIG. **15**. The apertures are adapted for a cementitious mixture spraying process, i.e. the apertures are adapted to the dynamic pressure during the spraying process, as well as to the hydro-static pressure of the accumulated material.

In use, a fresh cementitious mixture is conveyed through the hose **120** and is pneumatically projected at high velocity onto a surface of the mesh formwork **115**. The fresh cementitious mixture coats the filaments of the formwork **115**. The apertures are larger on the front section of the formwork **115** (as seen from the hose **120**) for the Shotcrete to easily enter the cavity formwork **115**. The apertures on the back section of the formwork **115** are smaller to prevent the concrete from shooting through the mesh. The apertures on both the front and the back sections is further adapted to the hydro-static pressure of the accumulated Shotcrete.

In another embodiment, instead of spraying, the fresh cementitious mixture is pressed onto the mesh from the outside of the mesh towards the inside of the mesh either by a trowel or by a concrete pump from a distance d of, for example, about 10 cm.

In one implementation, the fresh cementitious mixture covers and closes the apertures of the formwork **115**.

FIG. **17** shows an extruded mesh formwork **115** being filled with fresh cementitious mixture from a hose **161** from the top of the formwork **115**.

The formwork **115** comprises a plurality of filaments in which the filaments define apertures. The apertures are adapted for a cementitious mixture filling process, i.e. the apertures are adapted to the dynamic pressure during the filling process, as well as to the hydro-static pressure of the accumulated material.

In use, the fresh cementitious mixture is conveyed through the hose **161** and is pneumatically projected at moderate velocity into the cavity of the mesh formwork **115**, as shown in FIG. **17***a*). The fresh cementitious mixture fills the cavity up to a selected first height, which levels, after being conventionally treated with a concrete vibrator **163**, as a first layer **164**, as shown in FIG. **17***b*).

Next, fresh cementitious mixture is again conveyed through the hose **161** and is projected at moderate velocity, into the cavity of the mesh formwork **115**, and on top the first layer **164**, as shown in FIG. **17***c*). The first layer is not allowed to entirely harden prior to the next filling of fresh cementitious mixture, so as to preferably ensure that a structurally homogenous 3-dimensional structure is formed upon hardening. The fresh cementitious mixture now fills the cavity up to a selected accumulated height, which levels, optionally facilitated by application of the concrete vibrator **163**, as shown in FIG. **17***d*). This optionally temporarily increases the fluidity of the cementitious mixture, which also facilitates spreading or protruding of the cementitious mixture through the apertures, which in turn facilitates embedding of the mesh formwork **115**.

This process is repeated until the entire mesh formwork is filled.

As the formwork **115** is produced by a robot using extrusion, the formwork **115** can have various shapes. This is unlike other formwork techniques, which can only produce certain shapes at low cost.

FIG. **18** shows a reinforcement formwork **120** for producing a reinforced concrete structure.

The reinforcement formwork **120** includes an extruded mesh formwork **122** that is fabricated by the robot **10** and a plurality of reinforcement structures **125**, such as metal bars and/or meshes, wherein the reinforcement structures **125** are inserted in the mesh formwork **122**, as illustrated for better clarity in the sequential diagrams on the left side of FIG. **18**. In one method of using the reinforcement formwork **120**, the reinforcement structures **125** are inserted in the mesh formwork **122**. After this, fresh cementitious mixture is poured inside the mesh formwork **122**. The mesh formwork **122** holds the fresh cementitious mixture while a small portion of the fresh cementitious mixture seeps through apertures of the mesh formwork **122**. The fresh cementitious mixture essentially takes the shape of the mesh formwork **122** while the mesh formwork **122** and the reinforced structures **125** are embedded in the cementitious mixture. When the cementitious mixture hardens, the cementitious mixture forms a reinforced concrete structure. The reinforcement structures **125** allow the finished concrete structure to have good tensional strength while the hardened cementitious mixture allows the finished cementitious mixture to have good compressive strength.

FIG. **19** shows a further reinforced formwork **130** for producing a reinforced concrete structure.

The reinforcement formwork **130** comprises an extruded reinforced mesh formwork **132** that is fabricated by the robot **10** and a plurality of reinforcement structures **135**. The reinforcement structures **135** are inserted in the reinforced mesh formwork **132**, as illustrated for better clarity in the sequential diagrams on the left side of FIG. **19**. The reinforced mesh formwork **132** is formed from a filament or filaments **137** that have good tensional strength.

The reinforcement formwork **130** can be used to produce a further reinforced concrete structure using a method that is similar to the above method.

The filament or filaments **137** and the reinforcement bars **135** allow the finished concrete structure to have good tensional strength. The filament or filaments **137** can also act to replace some of the reinforcement structures, thus reducing the number of reinforcement structures **135** used in the concrete structure. In effect, tensional forces are distributed or shared between the reinforcement structures **135** and the reinforcement formwork **130**.

FIG. **20** shows an extruded reinforced mesh formwork **140** for producing a reinforced concrete structure.

The robot **10** fabricates the reinforced mesh formwork **140** using an end-effector, for example in the form of an extrusion head or a bending and welding head. The mesh formwork **140** is formed from a filament or filaments **144** with good tensile strength.

In one method of using the mesh formwork **140**, a fresh cementitious mixture is poured into the mesh formwork **140**. The fresh cementitious mixture takes the shape of the mesh formwork **140**. The mesh formwork **140** is embedded in the cementitious mixture. After the cementitious mixture hardens, the cementitious mixture forms a concrete structure.

The filament or filaments **144** allow the finished concrete structure to have good tensional strength. The mesh formwork **140** acts as reinforcement element to strengthen the finished concrete structure, advantageously without the need to add any reinforcement structures.

FIG. **21** shows a further extruded mesh formwork **150**, which is produced by a robot. The formwork **150** is intended for producing a concrete structure.

The mesh formwork **150** comprises a plurality of filament sections, wherein the filament sections define different apertures **701**, **702**, and **703** at different heights or levels L**1**, L**2**, and L**3**, i.e. the apertures differ as a function of height. The dimensions of the apertures **701**, **702**, or **703** at the same level are essentially the same while the dimensions of the apertures **701**, **702**, and **703** at different levels L**1**, L**2**, and L**3** are different. For example, the apertures **703** at the level L**3** are bigger than the apertures **702** at the level L**2**, wherein the level L**3** is higher than the level L**2**. Similarly, the apertures **702** at the level L**2** are bigger than the apertures **701** at the level L**1**, wherein the level L**2** is higher than the level L**1**. In one implementation, the width of the apertures stays the same, while the height is gradually changing.

The apertures **701**, **702**, and **703** are adapted for holding a fresh cementitious mixture with a predetermined viscosity. The hydrostatic pressures of the cementitious mixture at different levels L**1**, L**2**, and L**3** are different. The hydrostatic pressure of a lower part of the cementitious mixture is higher than the hydrostatic pressure of a higher part of the cementitious mixture. The apertures **701**, **702**, or **703** at a particular level L**1**, L**2**, or L**3** are adapted to the hydrostatic pressures of the cementitious mixture at that level L**1**, L**2**, or L**3**. Because of this, the dimensions of the apertures **701**, **702**, and **703** at different heights L**1**, L**2**, and L**3** are different for adapting to different hydrostatic pressures of the fresh cementitious mixture at the respective levels.

In use, a fresh cementitious mixture with a pre-determined flow viscosity is poured into the formwork **150**, wherein the formwork **150** holds the fresh cementitious mixture.

A small portion of the fresh cementitious mixture then seeps or protrudes through the different apertures **701**, **702**, and **703** at different levels L**1**, L**2**, and L**3** at essentially the same flow rate, such that the cementitious mixture takes on the shape of, and embeds, the formwork **150**, i.e., without flowing out of the apertures to an extent that the fresh concrete "collapses" out of the formwork. Later, optionally after vibrating, troweling and/or smoothing to facilitate a better embedding of the formwork **150**, the cementitious mixture hardens to form the finished concrete structure.

The extrusion of the apertures **701**, **702**, and **703** has an advantage in that the extrusion allows different apertures **701**, **702**, and **703** to be fabricated for adapting to different hydrostatic pressures of the cementitious mixture at different levels L**1**, L**2**, and L**3**.

It is noted that the dimensions of the apertures may alternatively or additionally differ across the formwork **150** due to the desired 3-dimensional shape of the formwork, including that the sizes of the apertures can differ at the same height.

FIGS. **28***a*), *b*) and *c*) show a top view, a cross-sectional view and a perspective view of an extruded mesh formwork **750**, wherein the mesh formwork **750** comprises a mesh **755** with substantially vertical channels **760** and with channels **770**, which extend in a substantially horizontal direction at an inclination for facilitating distribution of the fresh cementitious mixture.

The channels **760**, **770** are defined by gaps between adjacent mesh structures inside the mesh formwork **750**, or by apertures of increased size compared to other regions of the mesh structure inside the mesh formwork **750**.

In use, the fresh cementitious mixture (not shown) is poured into the channels **760** from the top. The channels **760**, **770** are defined by regions in which no mesh structure is provided across the cavity between the opposing front- and back-sides of the mesh formwork **750**, or by mesh structures across the cavity between the opposing front- and back-sides of the mesh formwork **750** with larger apertures and/or reduced vertical density.

The channels or ducts **760** and **770** facilitate distributing the fresh cementitious mixture. In particular, the channels **760** receive the fresh cementitious mixture and allow the received fresh cementitious mixture to flow to inside parts of the mesh **755**. The channel **770** allows the fresh cementitious mixture to flow from the channels **760** to another inside part of the mesh **755**. In this manner, the mesh **755** is filled with the fresh cementitious mixture.

FIG. **29** shows a flowchart **2900** illustrating a method of fabricating a 3-dimensional structure, according to an example embodiment. At step **2902**, a mesh formwork element is provided such that a cavity bound by at least two opposing portions of the mesh formwork is formed. At step **2904**, a material is accumulated in the cavity. At step **2906**, the material is allowed to harden, wherein apertures in the at least two opposing portions of the mesh formwork element are adapted to the hydro-static pressure of the accumulated material or vice versa such that at least two surfaces of the hardened material substantially take on the respective shapes defined by the two opposing portions of the mesh formwork element.

The material may protrude through the apertures before hardening. The material may embed the mesh formwork element such that the mesh formwork element re-enforces the 3-dimensional structure.

The mesh formwork element may comprise an irregular arrangement of the apertures providing a desired 3-dimensional shape of the mesh formwork element.

Providing the mesh formwork element may further comprise forming a mesh structure between the at least two opposing portions and across the cavity. The mesh structure may be connected to the at least two opposing surfaces of the mesh formwork element for supporting the at least two opposing surfaces in their respective shapes. A size of apertures in the mesh structure may differ from a size of the apertures in the at least two opposing portions of the mesh formwork element near the connections to the mesh structure. The method may further comprise providing one or more channel regions in the mesh structure to facilitate accumulating the material in the cavity. The channel regions may be defined by apertures of increased size compared to other regions of the mesh structure. The channel regions may be defined in gaps between adjacent mesh structures.

The mesh formwork element may be provided such that the cavity is bound by four surface portions of the mesh formwork element. The mesh formwork element may be formed from a filament material chosen for increasing tensile strength of the 3-dimensional structure. The mesh formwork element may comprise force locked filament sections for increasing tensile strength of the 3-dimensional structure. The force locked filament sections may comprise weld joints.

The method may further comprise inserting one or more re-enforcement structures in the mesh formwork element for increasing tensile strength of the 3-dimensional structure.

The size of the apertures in the at least two opposing portions of the mesh formwork element may vary, for example as a function of applicable force and/or a desired 3-dimensional shape.

The accumulating the material in the cavity may comprise providing a base surface through which the material can substantially not penetrate, the base surface bounding the cavity. The base surface may be provided by a foundation surface on which the structure is being fabricated.

The accumulating of the material may comprise filling the cavity with the material layer-by-layer. The material in one layer may not be allowed to fully harden before a next layer is provided directly adjacent said one layer.

The accumulating of the material may comprise pouring or spraying the material into the cavity. The material may comprise one or more of a group consisting of a cementitious mixture, a foam, and resin.

The method may comprise providing a mesh formwork structure comprising a plurality of the mesh formwork elements and accumulating the material in the respective cavities of the mesh formwork elements and allowing the material to harden.

The apertures in one or more of the at least two opposing portions of the mesh formwork element may be adapted to a dynamic pressure during the accumulating of the material or vice versa.

A mesh formwork element for fabricating a 3-dimensional structure according to an example embodiment comprises a cavity bound by at least two opposing portions of the mesh formwork element; wherein apertures in the at least two opposing portions of the mesh formwork element are adapted to the hydro-static pressure of a material intended to be accumulated in the cavity for formation of the 3-dimensional structure, such that at least two surfaces of the hardened material substantially take on the respective shapes defined by the two opposing portions of the mesh formwork element.

The mesh formwork element may comprise an irregular arrangement of the apertures providing a desired 3-dimensional shape of the mesh formwork element.

The mesh formwork element may further comprise a mesh structure between the at least two opposing portions and across the cavity. The mesh structure may be connected to the at least two opposing surfaces of the mesh formwork element for supporting the at least two opposing surfaces in their respective shapes. A size of apertures in the mesh structure may differ from a size of the apertures in the at least two opposing portions of the mesh formwork element near the connections to the mesh structure. The mesh formwork element may further comprise one or more channel regions in the mesh structure to facilitate accumulating the material in the cavity. The channel regions may be defined by apertures of increased size compared to other regions of the mesh structure. The channel regions may be defined in gaps between adjacent mesh structures.

The cavity may be bound by four surface portions of the mesh formwork element.

The mesh formwork element may be formed from a filament material chosen for increasing tensile strength of the 3-dimensional structure. The mesh formwork element may comprise force locked filament sections for increasing tensile strength of the 3-dimensional structure. The force locked filament sections may comprise weld joints.

The mesh formwork element may further comprise one or more re-enforcement structures for increasing tensile strength of the 3-dimensional structure.

The size of the apertures in the at least two opposing portions of the mesh formwork element may vary, for example as a function of applicable force and/or a desired 3-dimensional shape.

The mesh formwork element may comprise a base surface through which the material can substantially not penetrate, the base surface bounding the cavity.

The apertures in one or more of the at least two opposing portions of the mesh formwork element may be adapted to a dynamic pressure during the accumulating of the material.

A mesh formwork structure according to an example embodiment comprises a plurality of mesh formwork elements as described above.

A 3-dimensional structure according to an example embodiment comprises one or more formwork elements as described above.

FIG. **30** shows a flowchart **3000** illustrating a method of fabricating a formwork element for fabricating a 3-dimensional structure, according to an example. At step **3002**, a cavity is bound by at least two opposing portions of the mesh formwork element. At step **3004**, apertures in the at least two opposing portions of the mesh formwork element are adapted to the hydro-static pressure of a material intended to be accumulated in the cavity for formation of the 3-dimensional structure, such that at least two surfaces of the hardened material substantially take on the respective shapes defined by the two opposing portions of the mesh formwork element.

The method may comprise providing an irregular arrangement of the apertures for a desired 3-dimensional shape of the mesh formwork element.

The method may further comprise providing a mesh structure between the at least two opposing portions and across the cavity. The method may further comprise connecting the mesh structure to the at least two opposing surfaces of the mesh formwork element for supporting the at least two opposing surfaces in their respective shapes. A size of apertures in the mesh structure may differ from a size of the apertures in the at least two opposing portions of the mesh formwork element near the connections to the mesh structure.

The method may further comprise providing one or more channel regions in the mesh structure to facilitate accumulating the material in the cavity. The channel regions may be defined by apertures of increased size compared to other regions of the mesh structure. The channel regions may be defined in gaps between adjacent mesh structures.

The method may comprise bounding the cavity by four surface portions of the mesh formwork element.

The mesh formwork element may be formed from a filament material chosen for increasing tensile strength of the 3-dimensional structure. The method may comprise force locking filament sections for increasing tensile strength of the 3-dimensional structure. The force locking of the filament sections may comprise welding joints.

The method may further comprise providing one or more re-enforcement bars for increasing tensile strength of the 3-dimensional structure.

The size of the apertures in the at least two opposing portions of the mesh formwork element may vary, for example as a function of applicable force and/or a desired 3-dimensional shape.

The method may comprise providing a base surface through which the material can substantially not penetrate, the base surface bounding the cavity.

The apertures in one or more of the at least two opposing portions of the mesh formwork element may be adapted to a dynamic pressure during the accumulating of the material.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive. Also, the invention includes any combination of features, in particular any combination of features in the patent claims, even if the feature or combination of features is not explicitly specified in the patent claims or the present embodiments.

For example, while cementitious mixtures have been described in the example embodiments, other materials such as foams or resins may be used in different embodiments.

The invention claimed is:

1. A method of fabricating a 3-dimensional structure, the method comprising:

providing a mesh formwork element such that a cavity bound by at least two directly opposing portions of the mesh formwork is formed;

accumulating a material in the cavity; and

allowing the material to harden;

wherein apertures in the at least two directly opposing portions of the mesh formwork element are adapted to the hydro-static pressure of the accumulated material or vice versa such that at least two surfaces of the hardened material substantially take on the respective shapes defined by the two directly opposing portions of the mesh formwork element, and

the size of the apertures in the at least two directly opposing portions of the mesh formwork element varies as a function of applicable force.

2. The method as claimed in claim **1**, wherein the material protrudes through the apertures before hardening.

3. The method as claimed in claim **2**, wherein the material embeds the mesh formwork element such that the mesh formwork element re-enforces the 3-dimensional structure.

4. The method as claimed in claim **1**, wherein the mesh formwork element comprises an irregular arrangement of the apertures providing a desired 3-dimensional shape of the mesh formwork element.

5. The method as claimed in claim **1**, wherein providing the mesh formwork element further comprises forming a mesh structure between the at least two directly opposing portions and across the cavity.

6. The method as claimed in claim **5**, wherein the mesh structure is connected to the at least two directly opposing portions of the mesh formwork element for supporting the at least two directly opposing portions in their respective shapes.

7. The method as claimed in claim **6**, wherein a size of apertures in the mesh structure differ from a size of the apertures in the at least two directly opposing portions of the mesh formwork element near the connections to the mesh structure.

8. The method as claimed in claim **5** further comprising providing one or more channel regions in the mesh structure to facilitate accumulating the material in the cavity.

9. The method as claimed in claim **8**, wherein the channel regions are defined by apertures of increased size compared to other regions of the mesh structure.

10. The method as claimed in claim **8**, wherein the channel regions are defined in gaps between adjacent mesh structures.

11. The method as claimed in claim **1**, wherein the mesh formwork element is provided such that the cavity is bound by four surface portions of the mesh formwork element.

12. The method as claimed in claim **1**, wherein the mesh formwork element is formed from a filament material chosen for increasing tensile strength of the 3-dimensional structure.

13. The method as claimed in claim **12**, wherein the mesh formwork element comprises force locked filament sections for increasing tensile strength of the 3-dimensional structure.

14. The method as claimed in claim **13**, wherein the force locked filament sections comprise weld joints.

15. The method as claimed in claim **1**, further comprising inserting one or more re-enforcement structures in the mesh formwork element for increasing tensile strength of the 3-dimensional structure.

16. A method of fabricating a 3-dimensional structure, the method comprising:

providing a mesh formwork element such that a cavity bound by at least two directly opposing portions of the mesh formwork is formed;

accumulating a material in the cavity; and

allowing the material to harden;

wherein apertures in the at least two directly opposing portions of the mesh formwork element are adapted to the hydro-static pressure of the accumulated material or vice versa such that at least two surfaces of the hardened material substantially take on the respective shapes defined by the two directly opposing portions of the mesh formwork element, and

the size of the apertures in the at least two directly opposing portions of the mesh formwork element varies as a function of a desired 3-dimensional shape.

17. The method as claimed in claim **1**, wherein the accumulating the material in the cavity comprises providing a base surface through which the material can substantially not penetrate, the base surface bounding the cavity.

18. The method as claimed in claim **17**, wherein the base surface is provided by a foundation surface on which the structure is being fabricated.

19. The method as claimed in claim **1**, wherein the accumulating of the material comprises filling the cavity with the material layer-by-layer.

20. The method as claimed in claim **19**, wherein the material in one layer is not allowed to fully harden before a next layer is provided directly adjacent said one layer.

21. The method as claimed in claim **1**, wherein the accumulating of the material comprises pouring or spraying the material into the cavity.

22. The method as claimed in claim **21**, wherein the material comprises one or more of a group consisting of a cementitious mixture, a foam, and resin.

23. The method as claimed in claim **1**, the method comprising providing a mesh formwork structure comprising a plurality of the mesh formwork elements and accumulating the material in the respective cavities of the mesh formwork elements and allowing the material to harden.

24. The method as claimed in claim **1**, wherein the apertures in one or more of the at least two directly opposing portions of the mesh formwork element are adapted to a dynamic pressure during the accumulating of the material or vice versa.

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